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CYCLOPEDIA

OF

Modern Shop Practice

A Manual of

SHOP PRACTICE, PATTERN MAKING, MACHINE DESIGN, FOUNDRY
AND MACHINE SHOP WORK, FORGING, TOOL MAKING,
SHEET METAL WORK, STEAM, GAS AND OIL
ENGINES, AUTOMOBILES, ELEVATORS,
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Illustrated with over Two Thousand Engravings

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Introductory Note

THE successful education of the man in the shop is a question of vital importance. The difficulties under which he toils in his struggle for advancement, and his daily labor, render impossible the usual means of education, and prevent the attending of a resident technical school. Probably the most successful substitute for such a school is the correspondence method of instruction.

¶ Thousands of mechanics are improving their condition by devoting a half hour each day to systematic study under the direction of men who have had long experience in teaching, and in practical shop work. There are, however, many who cannot afford the time and expense necessary for a correspondence school course. For such the Cyclopedia of Modern Shop Practice is prepared.

¶ The instruction papers forming the Cyclopedia have been prepared especially for home study by acknowledged authorities, and represent the most careful study of actual shop needs and conditions. Although primarily intended for correspondence study, many are in use as text books by Harvard University, Columbia University, Lehigh University, Iowa State College, the University of Maine, the U. S. Government in its School of Submarine Defense, the Westinghouse Companies in their Shop School, and for reference in the leading colleges, shops and public libraries.

¶ Years of experience in the shop, laboratory, and class-room have been required in the preparation of the various sections of the Cyclopedia. Each section has been tested, by actual use, for its practical value to the man who desires to know the latest and best practice in the shop or engine room.

¶ Numerous examples for practice are inserted at intervals; these, with the test questions, help the reader to fix in mind the essential points, thus combining the advantages of a text book with a reference work.

¶ Grateful acknowledgment is due to the corps of writers and collaborators, who have prepared the many sections of this work. The hearty co-operation of these men—engineers of wide practical experience and acknowledged ability — has alone made these volumes possible.

¶ The Cyclopedia has been compiled with the idea of making it a work thoroughly technical yet easily comprehended by the man who has but little time in which to acquaint himself with the fundamental branches of practical engineering. If, therefore, it should benefit any of the large number of workers who need, yet lack, technical training, the editors will feel that its mission has been accomplished.

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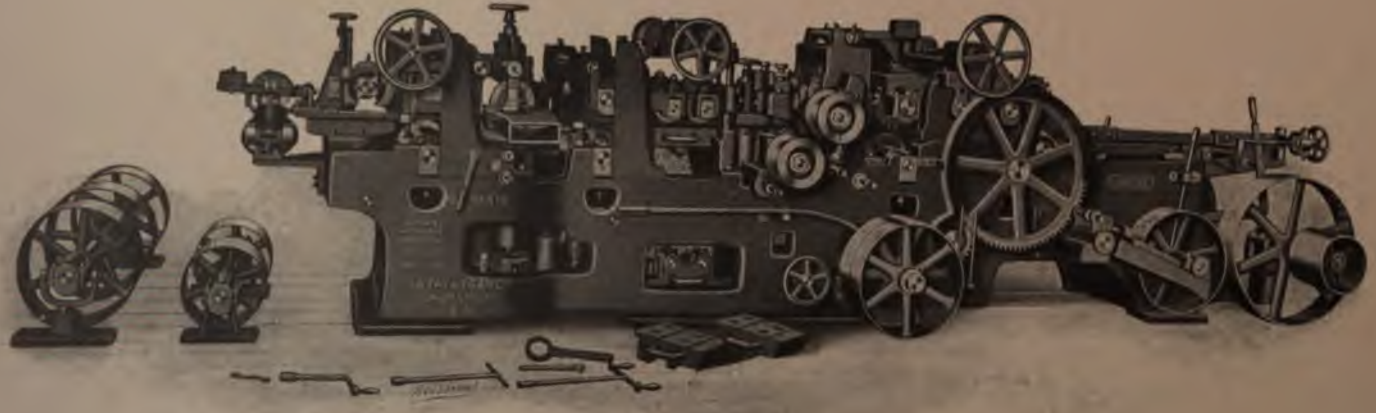

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PATTERN MAKING.

PART I.

PATTERN MAKING dates back to the time when the first article was made from molten metal for the use of man. The pattern must precede the making of its metal counterpart, and is therefore the first subject to be treated in the working of metal.

Qualifications of the Pattern Maker. The pattern maker is essentially a worker in wood, though, where many castings are to be made from the same pattern, the final or working pattern is made of metal. These metal patterns are very serviceable, and leave the sand more easily and cleanly than those made of wood. Metal patterns are always necessary when the work is of a delicate or very light character. In all such cases, however, the first pattern —from which the metal pattern is to be moulded—is made of wood, allowance being made for double shrinkage, and, when necessary, for double finish. The necessity for this will be clearly explained farther on.

The pattern maker should possess a practical knowledge of the properties of metals. First of all, he must understand the **shrinkage** of metals, that is to say, how much smaller the cold casting will be than the molten mass as it flows into the mould; he should know what the **strength** of the metal is; he should be familiar with the relative **rapidity of cooling,** so that internal stresses in the body of the completed casting may be avoided as much as possible; he also should know enough about the practical work of the moulder to decide upon the peculiarities of construction of the pattern for any given piece; and he must be sufficiently skilled as a draftsman to lay out, without the assistance of the designer, the drawings of the piece to be made. It is very true, however, that there are many good pattern makers who do not possess all of these qualifications.

The last-mentioned qualification is one of the most important. The drawings furnished the pattern maker are usually on a small scale.

In order to work to the best advantage, he must reproduce a part or all of them at full size, as working drawings. To do this in such a way that the lines and curves of the finished pattern shall be graceful and artistic in appearance, will require the same nicety and precision of workmanship that are demanded in the drafting room, and it is essential that the pattern maker have the same complete knowledge of the principles involved. To the extent, then, of being able, when necessary, to make a full-sized drawing of the article to be made, the pattern maker must be a draftsman.

In large establishments, where all the work comes to the pattern shop in the form of carefully executed drawings, the pattern maker is the means of putting the ideas of others into tangible shape. In smaller places, where no draftsman is employed, the pattern maker will be called upon to work out the designs for which he is to make his patterns, and he thus becomes the real designer.

Finally, the pattern maker is seldom required to make two patterns that are identically the same. His work, therefore, is varied, and he must be prepared to apply to the solution of new problems that arise such principles as he may already have learned.

Materials for Patterns. As patterns are subjected to more or less rough usage, and are alternately wet and dry, it follows that the ideal material is one whose hardness is such that it will withstand the wear and tear of handling and at the same time be impervious to the effects of moisture. Such material is to be found in the metals, but, as the cost of working these into the proper shape is considerable, some kind of **wood** is usually substituted.

Kind of Wood Used. If, then, wood is to be used, another qualification is to be added—namely, it should be easily worked. The best wood for the purpose is undoubtedly **white pine.** Care should be exercised in the inspection of the wood, to see that it is **clear, straight-grained,** and **free from knots.**

The straightness of the grain can be determined by the appearance of the sawn face. This should present an even roughness over the whole surface. The wood should be ***seasoned*** in the open air, but preferably sheltered by a roof, and should be piled so that the air will have free access to all parts of the plank. In the natural process of air drying, the moisture slowly works out to the surface and evaporates until the wood is dry or "seasoned." Such stock is firmer, stronger, more elastic, and less affected by heat and cold and by moisture and dryness, than kiln-dried lumber. In kiln drying, the outside surfaces and ends of the boards are dried more rapidly than the inside, producing strains that cause the wood to bend and warp while the pattern is in the process of construction. For this reason it is better to "build up" the larger pieces of a pattern by gluing together three or more (*never two*) pieces of thinner stock. When the patterns are of moderate size the stock to be glued may vary from 3/8 inch to 1 inch or even 1 1/4 inches in thickness, in proportion to the size required. Stock of 2 inches thickness or over can seldom be found sufficiently seasoned; and, if forced by kiln-drying, it will be checked and strained to an extent that will render it useless for pattern work.

While pine is in general the ideal wood for pattern work, it is soft and weak, so that, if small and strong patterns are desired, a harder wood is usually employed. **Mahogany** is much used for this purpose. Like pine, it is not liable to warp, and, when straight-grained, it is worked with comparative ease. There are many varieties of this beautiful wood, varying greatly in firmness of texture. The soft bay wood, often sold as genuine mahogany, should be avoided for patterns, being but little harder than pine. **Cherry** is also extensively used, but is not so easily worked to a smooth surface as mahogany, and is more liable than the latter to warp and to be affected by moisture. **Black walnut, beech,** and **maple** are used to some extent. Black walnut is stronger than cherry, but, like beech and maple, is likely to warp.

It may be stated then, that, in the United States, white pine is the material commonly employed for pattern making. Lumber 1 inch, 1 1/4 inches, and 1 1/2 inches thick will be found convenient in the construction of such patterns as are most commonly called for. It will be a great saving of time and labor, after the lumber has been carefully selected, to have it taken to the planing mill and dressed on two sides to the following thicknesses:

One-inch, dressed on two sides to 7/8 inch;
One and one-quarter-inch, dressed on two sides to 1 1/8 inch;
One and one-half-inch, dressed on two sides to 1 3/8 inch;

and, if such can be found well seasoned, a small quantity of two-inch, dressed to 1 3/4 inches.

In addition to these sizes there should be a moderate amount of 1-inch resawed and dressed to $\frac{5}{8}$ inch or to $\frac{5}{16}$ inch; and the same amount of $1\frac{1}{4}$-inch resawed and dressed to $\frac{1}{2}$ inch. The two last thicknesses are used for gluing and building up the rims of pulleys, gear wheels, and other light work where strength and durability are required.

Warping and Twisting of Wood. Observation shows that if one side of a board is kept damp and the other dried, the former will expand so that the plank, although originally straight, becomes curved as in Fig. 1. Or if one side of a board is exposed to the air, while the other is more or less protected, as in the stack of boards shown in Fig. 2, the exposed side of the upper board will give off its moisture more rapidly than the other side, and the board will warp or bend in the direction shown by the dotted lines. The second board will also "draw" and to some extent follow the first, being in turn followed by the third, and so on until the entire stack is warped and bent.

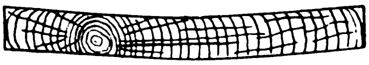


Fig. 1.

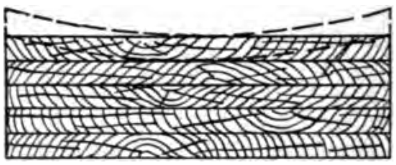


Fig. 2.

The same will be found true of a well-seasoned board if after being planed it is allowed to lie on its side on the work-bench. The upper side will give off its moisture more freely than is possible for the under side; the latter being protected and having its moisture retained by the bench. The lower side of the board is thus caused to expand, and the upper to contract, with the result that the board, although originally planed straight, becomes curved. For this reason all lumber, even if well-seasoned, should be so placed in racks, or on end, that the air may have free access to both sides of the planks; and newly planed boards, however dry and well seasoned, should never be stacked together, but so placed that both sides will be exposed alike.

This tendency to warp is explained to some extent by the porous nature of all woods, and their inclination to give off or to absorb moisture according to the condition of the surrounding atmosphere. As there is always more or less moisture in the air, and lumber of all kinds contains an amount of moisture which is ever changing according to the conditions of the surrounding atmosphere; this causes corresponding expansion or contraction of the wood.

Even under cover and in a dry place, wood has a tendency to warp on account of the greater shrinkage of the newer as compared with the older cells of the wood tissue or fiber in the side of the board nearest to the outside or sap wood of the tree. The inner side A of the board (Fig. 3) being closer to the heart wood, is older than the side B; its cells are firmer and more compact than those of B. As the board seasons, the newer and more open cells of the side B will shrink faster and to a greater extent than those of A, thus causing the board to draw or warp in the direction indicated by the dotted lines.

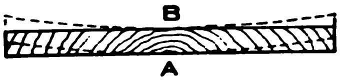


Fig. 3.

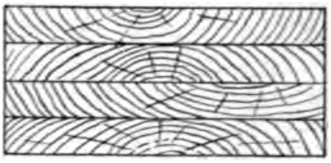


Fig. 4.

In gluing or building up stock for a pattern, this tendency may be corrected to some extent, by reversing the grain of the pieces that are to be glued, and placing two outsides (as B, Fig. 3) or two insides (as A, Fig. 3) together This is fully illustrated in Fig. 4.

In gluing very thin pieces together for the webs or centers of pulleys and for other purposes, it is often necessary to reverse the grain of the pieces, or to place the grain of *one piece at right angles to that of the other*, for the purpose of gaining greater strength and stiffness. In such cases, if only two thin pieces are used, the result, after they have been glued and dried, will be to some extent as shown in Fig. 5. the shrinkage and strain of the end grain crosswise of the board at *a*, being sufficient to bend the opposing thin board lengthwise of the grain at *b*, while on the side *cd*, the curve will be reversed for the same reason. *Whenever it is necessary to cross the grain of thin pieces for a pattern, three or more pieces should be used*, which will give satisfactory results if placed together as shown in Fig. 6.

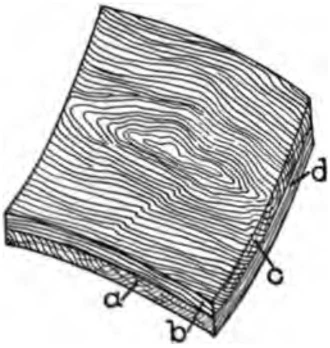


Fig. 5.

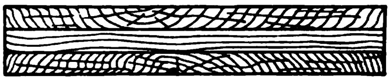


Fig. 6.

When thin circular disks of large size are to be glued up for patterns of any kind, the strongest, stiffest, and most satisfactory results will be obtained if the pieces are fitted and glued tangentially to the hub or other center or opening in the disk, as shown in Fig. 7. The grain of the wood must run lengthwise, and parallel to the longest side of each sector; and, after the pieces have been fitted together, a thin groove is cut in the edge of each, in which thin tongues of wood are inserted and glued, as illustrated in Fig. 8. Two disks are glued up, and one is turned over so as to reverse the grain of the sectors of one disk on that of the other, as shown by the dotted lines. The disks are then glued together, making a very rigid construction, and one which, owing to the continual change in the direction of the grain, will not warp.

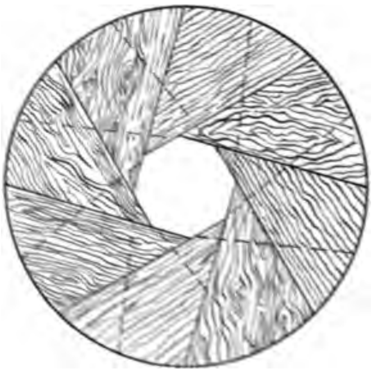


Fig. 7.

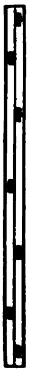


Fig. 8.

Should a wide and thin piece of a single thickness be required for a pattern, the board from which it is to be made should be ripped into strips of two, three, or four inches in width (according to the width of the required board), and the strips glued together again with each alternate strip reversed, as shown in Fig. 9. In this way the tendency to warp is to a great extent corrected, each narrow strip being inclined to warp in an opposite direction to that of its neighbor.

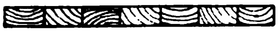


Fig. 9.

TOOLS.

While many of the tools used by the pattern maker are identical with those used by the carpenter and cabinet maker, yet the conditions that govern the construction of patterns for the molding of metals, together with the required accuracy in dimensions and the methods of construction used to guard against warping, distortion, and breaking, have very little in common with the workmanship and methods of the carpenter, the wood turner or the cabinet maker.

Following is a descriptive list of the more essential tools used in pattern making, accompanied with instructions in their use.

HAND SAWS.

Rip Saw and Crosscut Saw. Hand saws are of two kinds—**rip** and **crosscut.** The former, as the name indicates, is for cutting *with* the grain, or lengthwise of the board to be sawed. In Fig. 10 is illustrated a rip saw having 5½ points to the inch, which will work rapidly and with ease in pine and other soft woods. If mahogany, cherry, or other hard wood is to be ripped, a six-point saw should be used. Rip saws should be filed with all the bevel on the back of the tooth, as shown at *b* in Fig. 10, the front or "throat" of the tooth being at right angles to, or "square" with, the tooth edge of the blade, as at *a* in the same figure. The position of the line *cd*, whether perpendicular or slanting, is called the "hook" or "pitch" of the tooth.

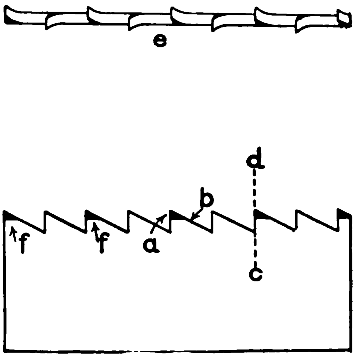


Fig. 10.

Rip saws should be filed square across; that is, the file should be held horizontal and at right angles to the side of the blade, always filing each alternate tooth from the opposite side of the saw; this, if done by beginning at the heel and working the file toward the point of the blade, will give a very slight bevel to the back edge of the tooth, causing it to cut cleaner and with less set than if filed otherwise.

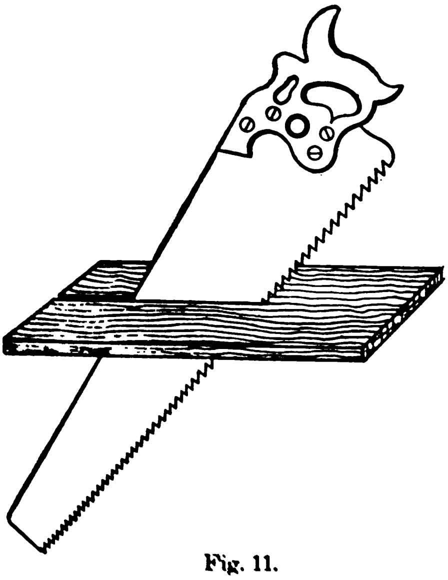


Fig. 11.

Rip saws require very little set for use in dry, well-seasoned lumber, such as is always used in pattern making. The teeth should be "set," or bent, only at the points, as shown at *e* and *f* in Fig. 10; and in no case should the set exceed more than half the depth of the tooth.

When the points only are set, the saw will work more freely, and the blade of the saw will not be "sprung," or bent, in setting. In using a rip saw, the front or cutting edge of the saw blade should be held at an angle of about 45° to the board, as shown in Fig. 11. This brings the back of the tooth nearly at right angles to the fibres of the wood, and insures a shearing cut. For fine work and well seasoned material, hand saws may be bought ground so thin on the back as to require no set. Such tools work very smoothly and easily, cutting away less wood and doing better work than saws that have been set.

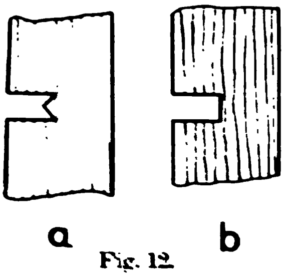


Fig. 12.

The crosscut saw really severs or cuts the fibres of the wood twice, as shown at *a* in Fig. 12, the intervening projections being loosened and carried out as dust by the thrust of the saw, producing a nearly straight bottomed kerf, as shown at *b* (Fig. 12).

A crosscut saw for ordinary work should have five or six points to the inch; but for fine work ten or twelve points would be better, especially for dry woods, either soft or hard.

A section of a 6-point crosscut saw is shown in Fig. 13, and one of an 13½-point in Fig. 14.

In considering rip saws we find that the rake or bevel is all on the back of the tooth. In crosscut saws the rake is on the side of the tooth, as shown at *a* (Fig. 13.) In ripping, the point of the tooth acts as a chisel, cutting off the fibers of the wood, each tooth chiseling off a shaving as it passes through the board; but in crosscutting, the side of the tooth does the cutting, and therefore must have its bevel on the side.

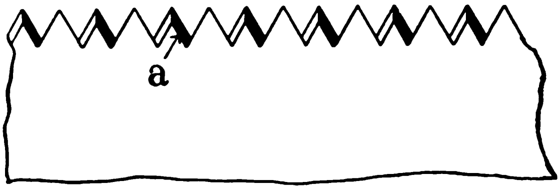


Fig. 13.

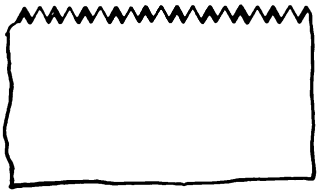


Fig. 14.

In Fig. 13 the bevel or **fleam** of the tooth is about 45°, and, as shown, there is no hook or pitch, the angle being the same on both the front and back of the tooth. This form of tooth works well in wet or in very soft wood; but for wood that is well seasoned, and for all the harder and firmer woods, the pitch of the front of the tooth should be at an angle of about 60° to the tooth edge of the blade, as shown in Fig. 15, and at *b* in Fig. 16. The amount of pitch in the teeth of a saw may be varied as demanded for different purposes or for different woods, but in all cases should be such as

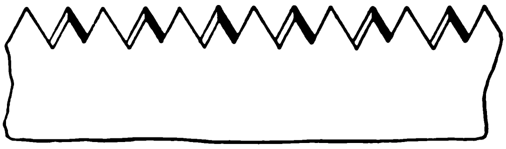


Fig. 15.

to loosen and carry out the intervening wood. Otherwise this would have to be rasped or filed out by the continued action of the saw.

The fleam of the side of the crosscut saw tooth is very important. When filing, the file should be held horizontally and at an angle of about 45° to the side of the saw, lengthwise of the blade, as illustrated in Fig. 16; and each alternate tooth must be filed from the opposite side of the blade, beginning at the heel and filing toward the point of the saw.

The objection is often raised by saw filers, that in filing from the handle end of the saw toward the point, a feather edge is made by the file and turned backward on the point of the tooth. The first thrust of the saw through the board, however, will remove this feather edge entirely; whereas, if the filing be done from the point of the saw toward the handle, it is necessary to file the teeth bent toward the operator, which causes the saw to vibrate, or "chatter;" and this not only renders good, even filing impossible, but breaks the teeth of the file.

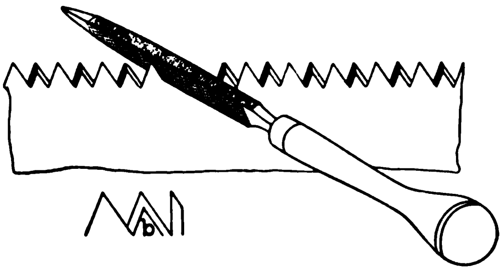


Fig. 16.

For hand and back saws, a saw-set that acts on the principle of the hammer and anvil, such as the one illustrated in Fig. 17, is best. The spring sets, so much in use, will not give so regular and even a set to the teeth as will one or more light blows with the hammer on the beveled face of the anvil. By this method the tooth is not bent or sprung beyond the position in which it is intended to remain, and the blade of the saw is not bent or affected by the stroke of the hammer on the point of the tooth. A saw-set of the kind illustrated in Fig. 17 can be adjusted to set the points of the teeth to any depth desired; and, even if repeated light blows are given, the tooth cannot be bent beyond the required distance. The blow may be struck on *a* with a light mallet; or it may be struck from below with the operator's foot on a treadle connected with *c*, leaving both hands free to hold and to guide the saw.

In setting a saw, it is always better to use two or three light blows on a tooth than to try to do the work with one heavy blow; and this is especially the case if the saw is hard, as all good and well-tempered saws should be.

The **back saw** illustrated in Fig. 18 is used as a bench saw for light or fine work, and for fitting and dovetailing. Saws of this type are made from 8 to 14 inches in length, the 10- and 12-inch being convenient sizes for general work. As the metal back holds and stiffens the saw, a thin blade should always be selected; and the methods of filing, jointing and setting are the same as already described for hand saws. At least two back saws will be found necessary, one filed for crosscutting, and the other filed as a rip saw for cutting *with* the grain of the wood, as in the cutting of tenons and dovetails.

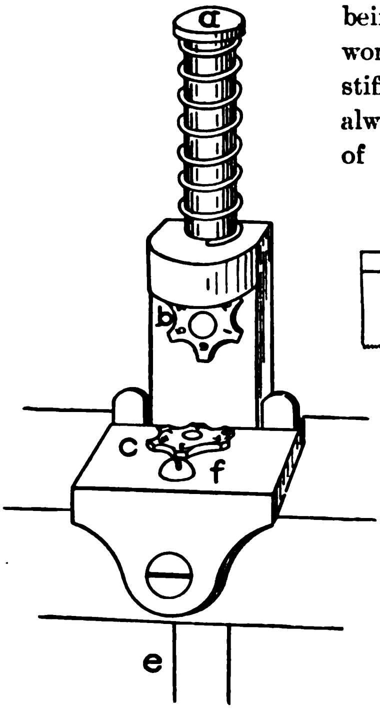


Fig. 17.

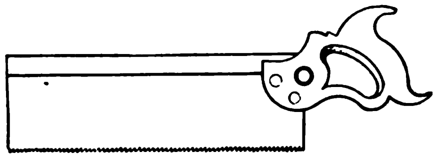


Fig. 18.

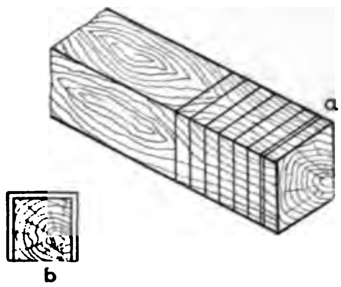


Fig. 19.

EXERCISE.

While for those who have had experience in carpentry the following exercise in the use of the back saw may not be necessary, it is recommended to all beginners who wish to acquire skill in the use of this important tool.

Take any block of wood from 12 inches to 16 inches long, about 2 inches wide, and about 1¾ inches in thickness. With try-square and a sharp-pointed pocketknife, lay it out as illustrated in Fig. 19, on the upper, front, and back sides of the block. The knife-cuts must be at least $\frac{1}{32}$ inch deep, and about ¼ inch distant from each other. Next proceed to saw up the block into thin sections, sawing each time so that the saw kerf will be just outside of, but close to the knife line, as indicated at *a*.

The saw-cut through the block should be true to each of the three lines; and while the saw passes along one side of the line, its teeth should not scratch the opposite side of the knife-cut, but should leave a smooth, clean angle of the knife-cut on the block, as shown at *b* in Fig. 19, while at the same time it should be so close to the line as to leave no wood to be smoothed off with plane or chisel.

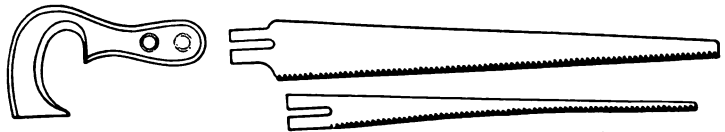


Fig. 20.

A few hours' thorough and careful practice of this exercise will enable any one to use the saw successfully.

Compass Saw. As the work of the compass saw, illustrated in Fig. 20, will be both *with* and *across* the grain of the wood, the best form of tooth will be that shown in Fig. 21, having more pitch, and slightly less bevel, than the crosscut saw. A crosscut saw will rip better than a rip saw will crosscut; hence the shape of tooth should be between the two. Compass saws are ground very thin on the back of the blade, but in order to turn easily they should be set the same as hand saws. And here we wish to impress on the beginner the necessity of keeping his saw and indeed all other cutting tools perfectly sharp and in good working condition at all times. A sharp saw will work faster, and will always do smoother and better work with less set and with less expenditure of power, than a dull one. Even to saw well is an art, which cannot be gained through the use of dull, imperfectly set, and poorly kept tools. To file well will require from the beginner close attention, a study of the subject, and careful practice, all of which

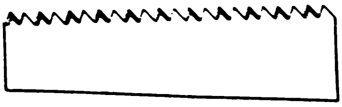


Fig. 21.

can be given by any one possessing ordinary mechanical ability. If the filing is done slowly at first, care being taken to hold the file at the same angle for all the teeth, a little faithful practice will always bring success.

PLANES.

The Iron Plane. The modern iron plane, illustrated in Fig. 22, can now be bought in a great variety of sizes and styles. These planes, with their true and unchanging faces, and their simple appliances for setting and adjusting the cutter (or **plane-iron**) to the face of the plane and to the required thickness of shavings, are greatly to be preferred to the old-style wooden planes.

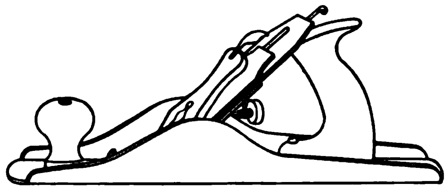


Fig. 22.

The general construction of the iron plane will be readily understood from Fig. 23, one side of the plane being removed to show the arrangement of the parts; *a* is the cutter, or plane-iron, which is made of the best cast steel and of equal thickness throughout. In all new planes this part will be found ground and sharpened for immediate use.

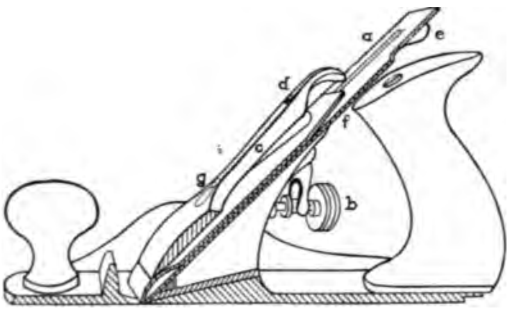


Fig. 23.

The cap-iron *f* (Fig. 23) is fastened to the plane-iron, by an adjusting screw, as shown in Fig. 24. For whetting or grinding the cutting edge, it is not necessary to remove the cap-iron,

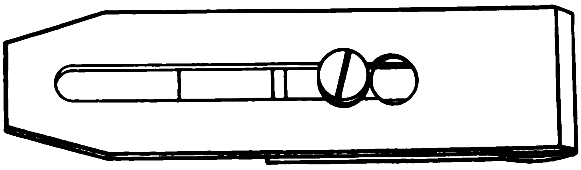


Fig. 24.

but only to loosen the connecting screw and to slide the cap back to the extreme end of the slot in the plane-iron, tightening it there by a turn of the screw. The cap-iron will then serve as a convenient handle or rest in whetting or in grinding.

The iron lever *c* (Fig. 23) is held in place below its center by the screw *g*, which acts as a fulcrum, and the lever is readily clamped down upon the irons by the use of the cam-piece *d*. When this cam is turned upward it ceases to bear upon the irons. The lever *c* may then be removed from its place, and the irons released, without turning or changing the adjustment of the screw *g*, as the lever and irons are properly slotted for this purpose.

Should the pressure required for the best working of the plane-iron need changing, it can easily be obtained by tightening or loosening the screw *g*.

When the plane-iron is secured in its place, the use of the brass thumb-screw *b* will *draw* or *drive* the plane-iron; and thus the thickness of the shaving to be taken from the work can be regulated with perfect accuracy. By the use of the lever *e*, located under the plane-iron, and working sidewise, the cutting edge can easily be brought into position exactly parallel with the face of the plane, should any variation exist when the iron is clamped down. To ascertain this, hold the plane up, and look down over its face; the greater projection, if there be any, of one or the other of the corners of the iron, can readily be seen.

The cap-iron *f*, which is not sharp, is *not*, as is often supposed, used for the purpose of strengthening or stiffening the cutting iron, but as a chip-break to prevent the cutting edge of the plane-iron from chipping, tearing, and breaking the grain of the wood below the surface when the grain turns and twists, or when it is knotty and crooked. In such cases the tendency of the plane-iron is to split and tear out the fibres of the wood in front of the cutting edge. To avoid this, the cap-iron is screwed on with its dull edge quite close to the cutting edge, so as to bend and break off the fibres or the shavings before the split gets fairly started below the surface.

The cutting edge of the plane-iron is said to have *lead* in proportion to the distance it is placed in advance of the dull edge of the cap-iron. The depth of the splits, or the roughness of the cross-grained surface, will be just equal to the lead of the cutting edge. For soft, straight-grained wood, the lead may be $\frac{1}{32}$ inch or even more, but this must be reduced in proportion as the wood is curly, cross-grained, or knotty.

The grinding, or the whetting, must always be done on the *bevel* side only of the plane-iron, the upper side being kept as flat and as smooth as possible to secure easy working.

All plane-irons should be ground slightly rounding to the extent of the thickness of a thin shaving. This rounding of the cutting edge should be the true arc of a circle throughout the entire length of the cutting edge, and not simply a rounding-off of the corners as is sometimes directed. Rounding the edge to the extent of the thickness of a shaving will prevent the plane-iron from grooving into, or plowing out a wide groove in, the surface that is being worked, and will also assist greatly in working the edges of the piece to right angles, or square with the face side. To do this it is not necessary, should one corner of the edge be higher than the other, to tilt the plane on the high edge, but, while holding it flat and firm on the surface of the edge being planed, push the plane sidewise towards the highest corner in order to reduce that corner. This will readily be understood when we remember that the cutting edge of the iron is rounding. If the plane is held so that the middle of the plane-iron will do the cutting, the shaving planed will be of the same thickness on both edges; but if the plane is pushed over to one side, either to the right or to the left, the shaving will be feather-edged, or thick on one edge and thin on the other, thus reducing the higher corner of the edge of the piece.

When the plane is to be used, the beginner should first carefully adjust it to the thickness of shaving required, by holding it up and looking down over the face of the plane, when the projection of the plane-iron can readily be seen, and then by testing on the piece to be planed.

The operator's position should be one of perfect ease, standing well back of the piece to be planed, and pushing the plane to arm's length *from* (not alongside of) the operator, taking long and continued shavings from the board. When starting the shaving at the end of the board, care should be taken to hold the forward end of the plane down firmly, or the act of pushing it forward will cause that end to tilt up and the plane-iron to chatter on the surface as it begins to cut the shaving. This is owing to the fact that nearly two-thirds of the plane overhangs the end of the board, requiring firm pressure on the forward end to balance it while the stroke is being started.

To insure smooth work, care must be taken to plane *with the grain* of the wood, and not *against* the ends of the fibres as they lie in the surface of the board. Should the fibres tear out and the surface become rough, reverse the ends of the boards so as to cut the shaving in the opposite direction, and note the difference in the effect on the planed surface.

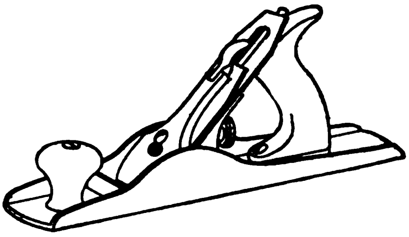


Fig. 25.

Of iron planes, the most important is the No. 5 **jack plane,** 14 inches long, and having a cutter 2 inches in width. This plane is illustrated in Fig. 25.

When the pattern lumber has first been roughly planed in a planing mill, this No. 5 plane almost exclusively can be used for planing and pattern making. In making or in "truing up" very large surfaces, however, or in making long glue joints, the No. 7 **jointer plane,** 22 inches long and having a cutter 2⅜ inches wide, will be found necessary. This plane is shown in Fig. 22, and differs from the jack plane only in its length and in its extra width of face.

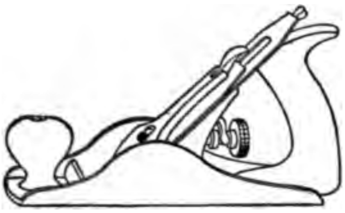
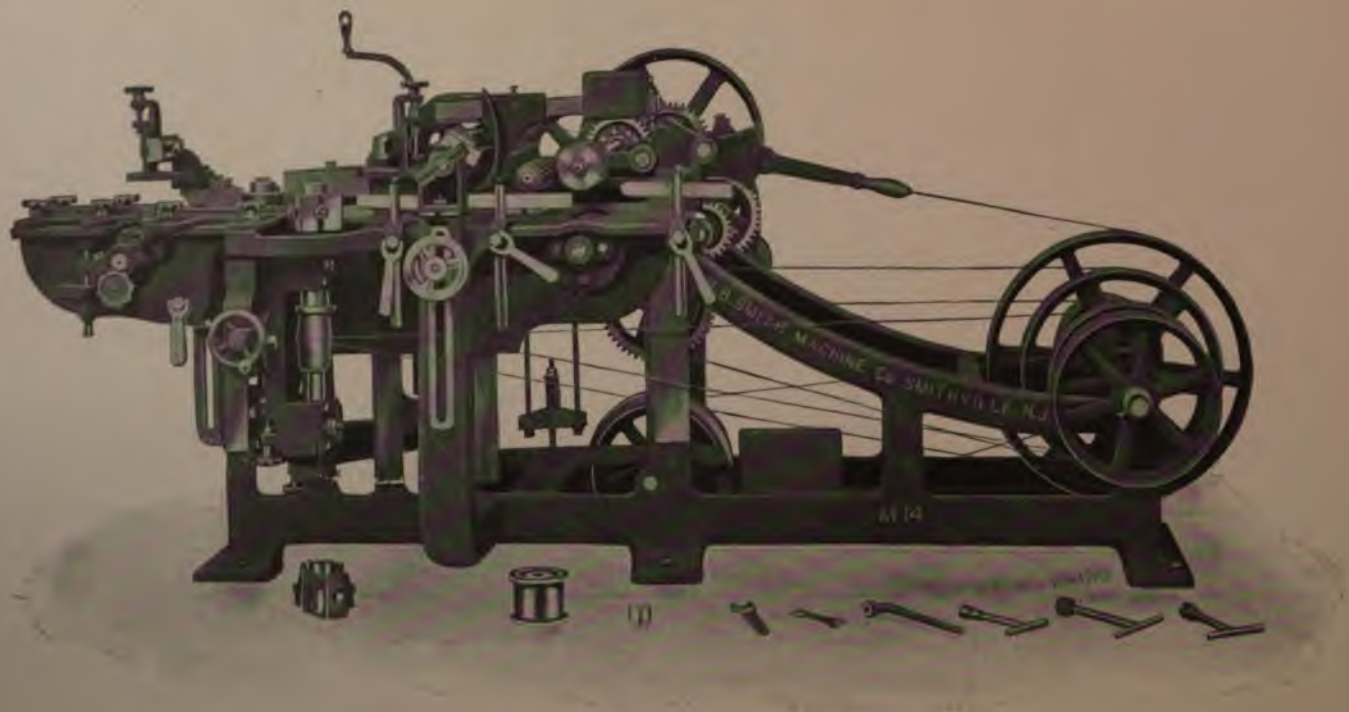


Fig. 26.

For mahogany or other hard wood, the No. 4 **smooth plane,** illustrated in Fig. 26, will be found very useful. This plane is made in several sizes. The No. 4, which is 9 inches long and has a 2-inch cutter, is the best size for general use.

Next in importance to the three planes already mentioned, is the **block plane,** illustrated in Fig. 27. The No. 19, which is 7 inches long and has a cutter 1¾ inches wide, is the most desirable for the pattern maker's use. It has an adjustable throat, as well as the screw and lateral lever adjustments of the other planes. This

ASTOR LENOX


H. B. SMITH MACHINE Co. SMITHVILLE N.J.
M 14

6-INCH MOULDING MACHINE.
H. B. Smith Machine Co.

plane has the advantage of being so constructed as to be held easily in one hand. Owing to the low angle at which the cutter is placed it works more smoothly and easily on end wood and on miters than any other plane.

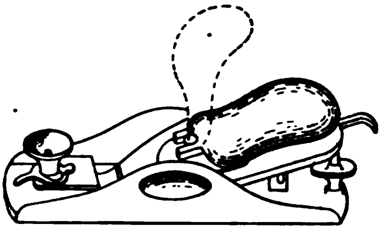


Fig. 27.

In cases where lumber must be dressed from the rough, without being first roughly dressed in a planing mill, the No. 40 **scrub plane,** illustrated in Fig. 28, will be almost indispensable. It is 9½ inches long, and has a cutter 1¼ inches wide. The cutter is a single iron, and is ground and sharpened very rounding on the cutting edge, as shown in Fig. 28, to allow of cutting a very thick shaving without grooving at the edges. This plane works rapidly and easily, preparing the rough-sawn surfaces of planks for the finishing planes.

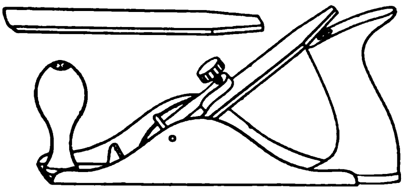


Fig. 28.

For truing and smoothing circular arcs and curves of all kinds, either convex or concave, there is no tool that equals the **circular plane,** illustrated in Fig. 29. This plane has a flexible steel face which can easily be shaped to any required arc or curve by turning the knob on the front of the plane.

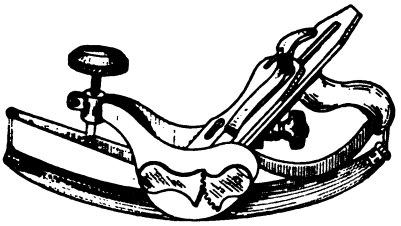


Fig. 29.

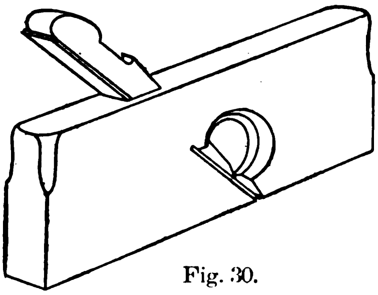


Fig. 30.

The Rabbet Plane. Among the special planes used by the pattern maker, the rabbet plane, illustrated in Fig. 30, is the most important. The face of this plane is always flat and at right angles to the sides. It is used in working out square angles and corners, or *laps* as they are called in carpentry, and also for working lap joints, as shown in Fig. 31.

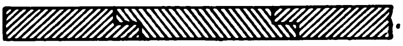


Fig. 31.

The skew-iron rabbet plane, in which the cutting edge of the plane-iron is set diagonally across the face of the plane, works much more smoothly and easily than one in which the iron is set at right angles to the side of the plane. The improved rabbet plane shown in Fig. 32 is fitted with depth gauge, and also with a spur cutter, both of which are often of great convenience to the workman.

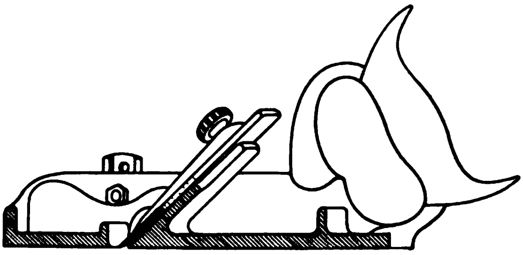


Fig. 32.

Rabbet planes are made in sizes ranging from ½ inch to 1½ inches in width. The 1-inch and 1¼-inch are convenient sizes for general work.

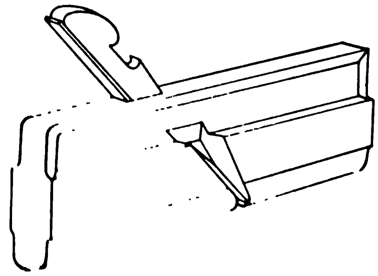


Fig. 33.

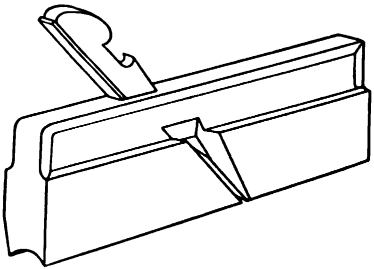


Fig. 34.

Round and Hollow Planes. These planes are illustrated in Figs. 33 and 34. They are made of different curvatures, and a set of assorted sizes, especially the *rounds*, are almost indispensable to the pattern maker for finishing semicircular core boxes, for making fillets, and for working out curves of every description, both concave and convex.

The Core-Box Plane. The core-box plane, shown in Fig. 35, while not indispensable, will be found to be a very rapid working and useful tool for making semicircular core boxes up to 2½ inches in diameter. By using the extension sides, one of which is shown in the illustration, and two pairs of which are always furnished, this tool will work accurately a concave semicircle up to 10 inches in diameter.

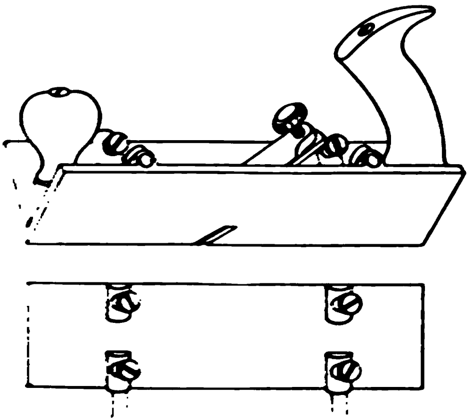


Fig. 35.

The core-box plane is constructed upon the principle that if the sides of a right angle lie upon the extremities of a diameter of a circle, the vertex of the right angle will lie upon the circumference of the circle. This is illustrated in Fig. 36, from which it will be seen that if the block of wood has been worked to a perfect semicircle, and the edges of the blades of a try-square or right-angled triangle touch the semicircular curve at its extremities,

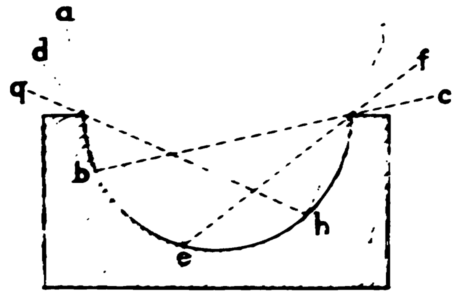


Fig. 36.

the right angle or corner will touch the arc at some point, as *b*, *e* or *h*, the angles *abc*, *def*, and *ghi* all being right angles.

To this kind of plane the objection is often made that it abrades and wears off the corners of the semicircle as it is being worked out. This, however, can be practically avoided if the following instructions are followed:

Carefully lay out the block from which the core box is to be worked, from a center line on the face of the block, describing on each end of the block a semicircle of the required radius; connect the extremes of the two end arcs by straight lines on the face of the block, as shown in Fig. 37. Two very thin strips of hard wood are tacked along these lines, just outside of the wood to be cut away, as shown at *a* and at *b* in Fig. 38. These strips form rests for the sides of the plane while the heavier part of the work is being done. After working out the semicircle as far as the strips will allow, as shown by the dotted arc *acb*, the strips are removed, when the work can be finished without materially affecting the corners at *a* and *b*.

When making the finishing cuts with this plane, care must be taken to adjust the cutter centrally, *i. e.*, so that it will cut equally to both right and left; otherwise the work will not be correct. If, however, the work has been done with care, the finishing may be completed with coarse, and lastly with fine, sandpaper held on a cylindrical block of radius slightly less than that of the required core box.

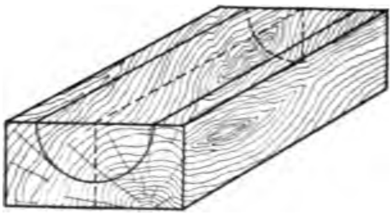


Fig. 37.

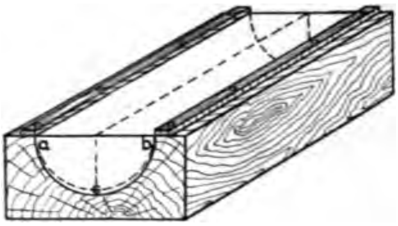


Fig. 38.

The Router Plane. This tool will be found very convenient for smoothing out sunk panels, for letting in rapping and lifting plates, and for all depressions below the general surface of the pattern. It will plane the bottoms of recesses to a uniform depth from the surface of the work, and will work into angles and corners that otherwise could be reached only by the use of the paring chisel. It is illustrated in Fig. 39.

The Spoke-Shave. The spoke-shave is used by the pattern maker for shaping and rounding out small curves either convex or concave, which cannot be reached with the circular plane. It can be found in a great variety of styles, either in metal, as shown in Fig. 40, or in wood. The all-wood boxwood spoke shave illustrated in Fig. 41, without brass facing or screw adjustment, is to be preferred to all others for the pattern maker's use, especially for working pine or other soft wood.

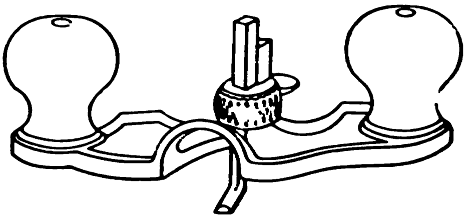


Fig. 39.

CHISELS AND GOUGES.

The chisel enters so largely into the work of the pattern maker in paring and shaping patterns that the quality of the tool should be of the best. While carpenters' chisels are made in several styles, they may be divided into two general classes, **socket-handled chisels,** and **firmer** or **paring chisels.** The former are illustrated in Fig. 42, and are used for framing, and for very heavy work of all kinds in which the use of a mallet is necessary. The common firmer or paring chisels, two styles of which are shown in Fig. 43, are the best all-round chisels for pattern work. Being lighter and

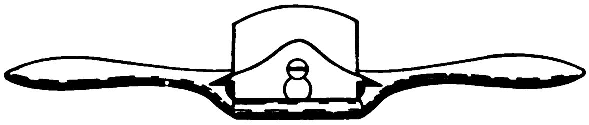


Fig. 40.

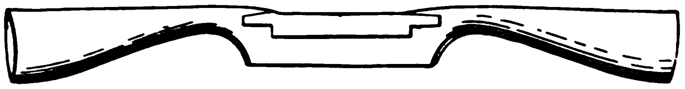


Fig. 41.

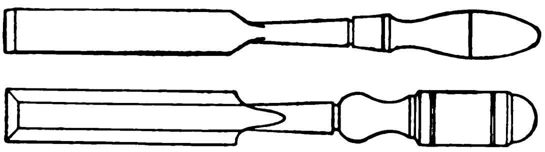


Fig. 42.

thinner than the others, they are better adapted to the light work on which they are used; moreover, when used with care, they will answer every desired purpose, even for heavy work or with a mallet.

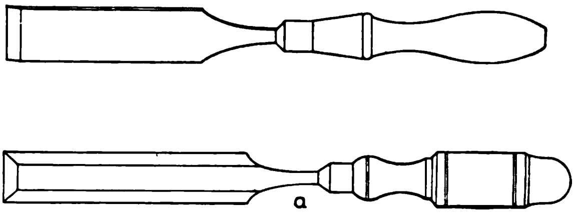


Fig. 43.

The beveled-edge chisel shown at *a*, Fig. 43, is greatly to be preferred. It is lighter than the other kind illustrated, and the square angle being removed, the workman is enabled to reach into angles and under projections difficult to reach with a square-edged tool. A set varying in width from ⅛ inch to ⅝ inch by eighths, and from ¾ inch to 1½ inches by quarters, nine chisels in all, will be found useful.

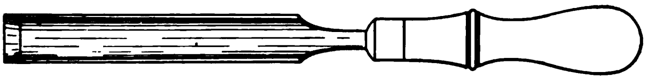


Fig. 44.

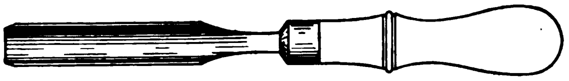


Fig. 45.

The paring gouges used in pattern making are ground or beveled on the inside, as shown in Fig. 44. These gouges are made in **regular, middle,** and **flat** sweeps. They are indispensable for working out core boxes and other curves.

In selecting a set of paring gouges, they should be not only of assorted sizes, but of different sweeps, so as to work out semicircles and curves of different radii

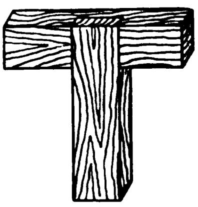


Fig. 47.

The common firmer gouge, illustrated in Fig. 45, is a useful tool for rough or heavy work, but in general its use can be dispensed with in pattern making.

The manner in which the chisel is used is so obvious and simple that any instruction in that direction would seem unnecessary. We shall only say in a general way that in using a chisel on a flat surface or in a recess it should always be held with the flat or back of the chisel against the work: and, whenever possible, it should not be pushed straight forward or straight through an opening, especially when paring across the grain of the wood, but should be moved laterally at the same time that it is pushed forward, as indicated by the dotted lines in Fig. 46. This insures a shearing cut, which, with care, even when the material is cross-grained, will produce a smooth and even surface.

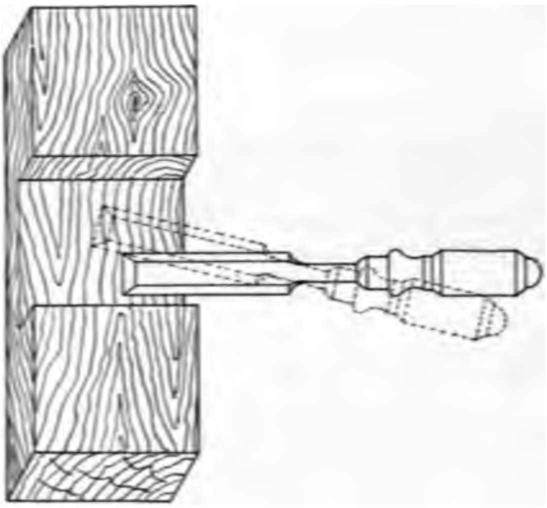


Fig. 46.

As an exercise for acquiring the free use of the paring chisel there is nothing better for the beginner than the simple half-lap joint shown in Fig. 47.

The shoulders or the ends of the openings must be cut with a back saw. The opening is then cut out and the shoulders smoothed with a wide chisel and a perfect fit obtained by continued trials.

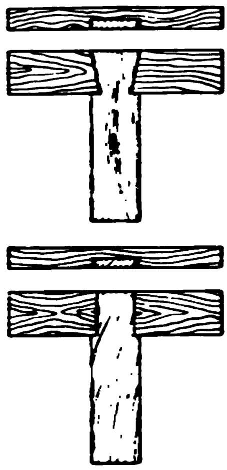


Fig. 48.

The two dove-tail joints shown in Fig. 48 may be attempted, after having succeeded with the half-lap; and these exercises should be continued by the student until such control of the chisel is attained that this and similar work can be done with ease and certainty. For laying out work of this kind the blade of a pocketknife or bench knife should always be used. This gives a clean, sharp-cut angle for the meeting sides of the joints, which cannot be obtained if a scratch-awl is used. The awl tears and breaks the fibres of the wood, producing a rough, ragged angle, which, on fitting, cannot produce a smooth and close piece of work. A pencil is equally objectionable because of the indefinite dimensions given by its use.

An assortment of four to nine carver's gouges, front bent as shown in Fig. 49, will be found necessary for working out short, deep curves, and in places where a straight gouge cannot be used, as in the core boxes for a globe valve, shown in Figs. 222, 223, 227, 228, and similar work.

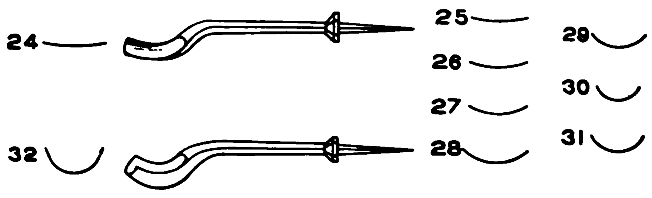


Fig. 49.

The full set consists of *nine* tools, the curves of which are numbered from 24 to 32. The two extremes, Nos. 24 and 32, are shown in Fig. 49, and also the shapes of the curves of the seven intermediates, Nos. 25 to 31 inclusive.

If desired, to save expense, each alternate tool might be omitted from the set, only the odd numbers 25, 27, 29 and 31 being selected. For ordinary work these will be found sufficient.

SQUARES.

The best try squares are now made with graduated blades, Fig. 50, and from two inches to twelve inches in length of blade. Several sizes will be found necessary, as in many cases the blade must be short to admit of its application in pattern work.

The adjustable try-square, illustrated in Fig. 51, is not expensive, and will be found to fill the requirements of several small squares. It is made in two sizes, with graduated blades four inches and six inches in length respectively. The blade of this square can be firmly secured in its seat at any point. When the blade is carried entirely to the front of the handle, it is like an ordinary try-square; and the moving of the blade makes the square equally perfect down to one-quarter-inch length of blade, or even less.

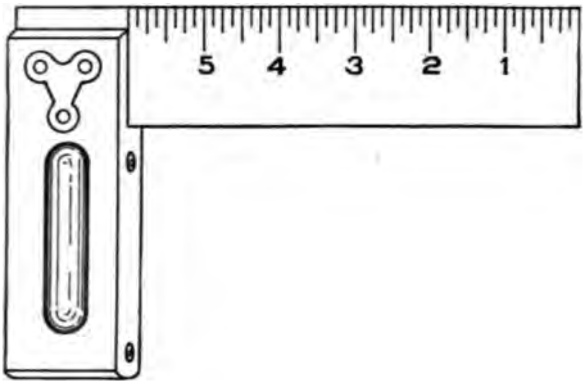


Fig. 50.

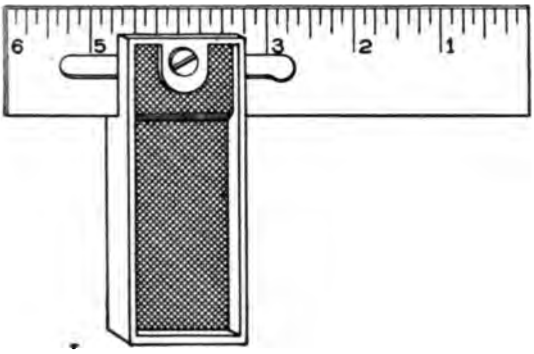


Fig. 51.

With one adjustable square of this kind, six inches in length, only one 8-inch or one 10-inch ordinary square will be found necessary.

A still more convenient, but slightly more expensive, form of adjustable try-square is shown in Fig. 52. It differs from that shown in Fig. 51, in being self-contained, no screw-driver being necessary for moving the blade or securing it in position, and also because the blade can be removed entirely, and an extra blade, shown in Fig. 53 substituted. The ends of this second blade give both the hexagon and octagon angles, which is a matter of great convenience to the pattern maker. Fig. 53 shows the hexagon end of the blade applied. Reverse the blade and the octagon end will be in position for use.

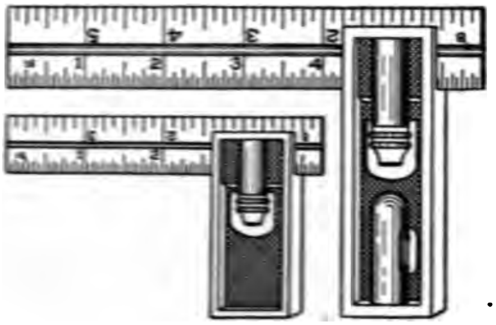


Fig. 52.

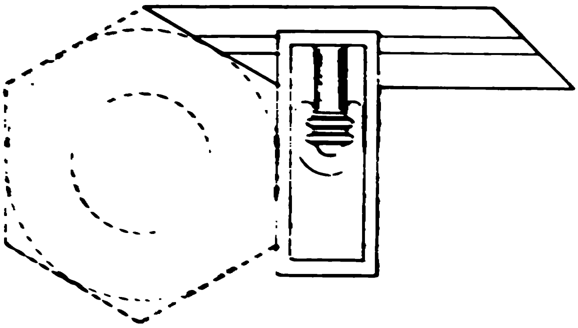


Fig. 53.

To the above try-squares there should be added a carpenter's steel square 24 inches × 18 inches for use in laying out and squaring up large stock and large patterns.

BEVELS.

The bevel illustrated in Fig. 54, with the clamping screw in the end of the handle, is the most accurate and the most easily adjusted style of this indispensable tool. The blades are made from 6 to 12 inches in length, and have a slot in one end, which admits of that end being shortened to meet the requirements of work.

The small **Universal bevel,** illustrated in Fig. 55, like the adjustable try-square, is not an expensive tool, and will be found generally useful, especially in working the draft on patterns, and in turning the parts of patterns on the wood lathe which cannot be reached with an ordinary bevel. The *set-off* in the blade increases its capacity and usefulness, so that any angle, however slight, can be obtained.

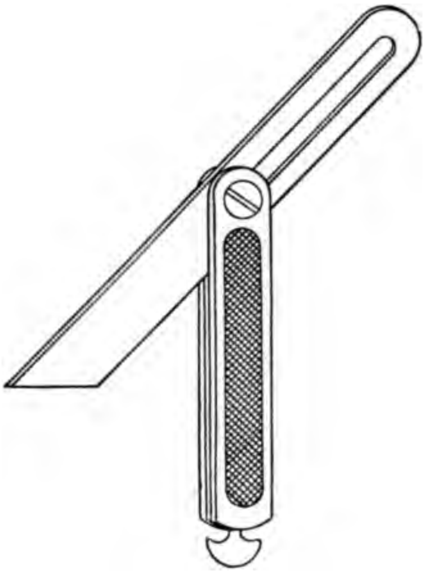


Fig. 54.

One 3-inch *Universal*, and one 8-inch or 10-inch ordinary bevel. will meet all the requirements of the pattern maker for the beveled edges and surfaces and the draft of pattern work.

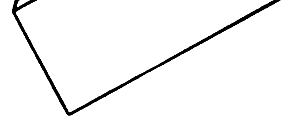


Fig. 55.

MARKING GAGES.

The marking gage is used for drawing a line at a given distance from, and parallel to, the already trued and jointed surface or edge of a board or piece of wood that is being marked to dimensions. There are many forms of this tool, but in the "Improved

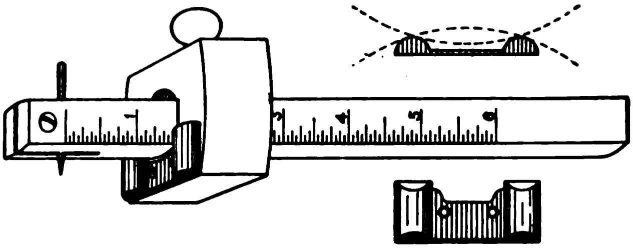


Fig. 56.

Marking Gage," illustrated in Fig. 56, the head is reversible. The flat side of the head is used for ordinary straight work, while the reverse side, having the brass face with two projecting ribs,

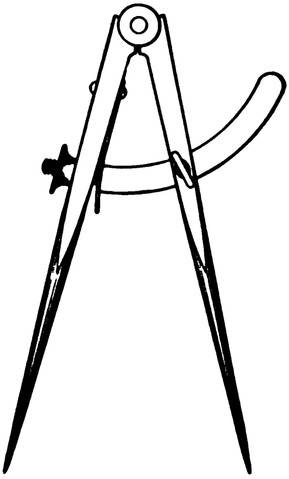


Fig. 57.

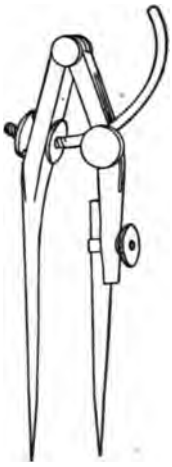


Fig. 58.

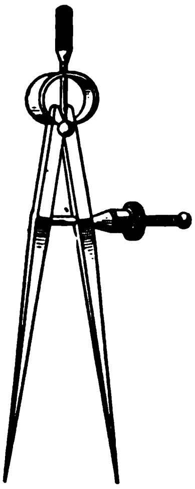


Fig. 59.

enables the operator to run a gage line with perfect steadiness and accuracy around curves of any radius, either convex or concave —a feature much to be desired in a pattern-maker's gage.

DIVIDERS AND TRAMMELS.

The ordinary wood-worker's dividers can be bought in many forms, the most common being the **screw-adjusting wing dividers,** shown in Fig. 57. This form is reliable, and is easily adjusted to the required distance between points. Moreover, when clamped by the thumb-screw, it is not liable to be altered by a slight blow in handling.

Another and improved form is shown in Fig. 58, one leg of which is removable so that a pencil can be inserted. This will be found very convenient for marking and laying out work.

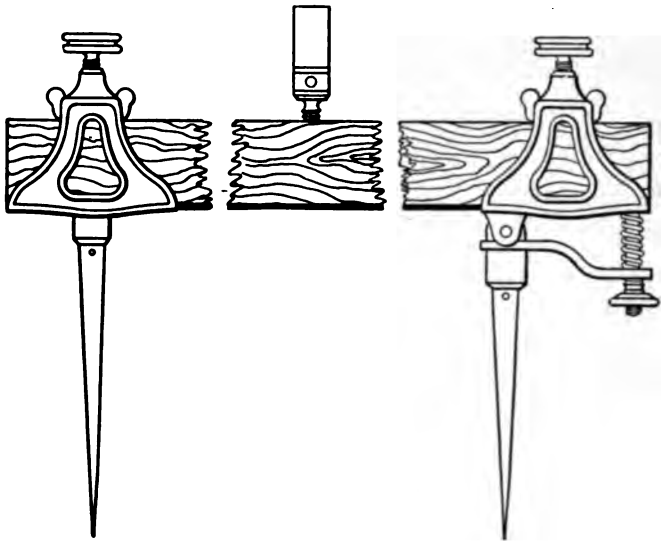


Fig. 60.

For spacing the teeth of gear wheels, and for other work in which great accuracy is required, a pair of 2½-inch or 3-inch dividers, such as are shown in Fig. 59, will be found necessary.

The **trammel** is used when the distance between the points to be reached is too great for the ordinary dividers. The trammel points are clamped to a beam of sufficient length to enable them to be set to the required distance apart. They may be bought with one adjustable point, as illustrated in Fig. 60; or without the screw adjustment, as in Fig. 61. The points are removable for the insertion of a pencil socket and pencil when needed.

For very accurate work, an excellent tool of this kind is illustrated in Fig. 62. The beams furnished are 4 inches and 13 inches in length. By the use of the cone center, shown at V, which may be substituted for the regular point, the tool can be used for scribing a line around any hole already bored—which is sometimes a matter of great convenience. The complete set includes the pen, pencil, straight and bent points, and the cone center, as shown in the cut.

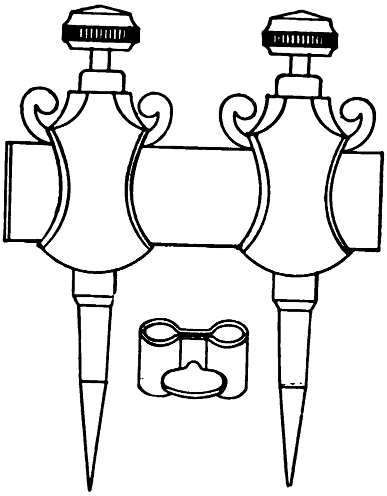


Fig. 61.

CALIPERS.

Calipers, like dividers, are made in many different forms, with and without screw adjustment. Fig. 63 illustrates the screw-adjusting wing calipers for outside measurements; and Fig. 64 the firm-joint outside calipers, used for the same purpose.

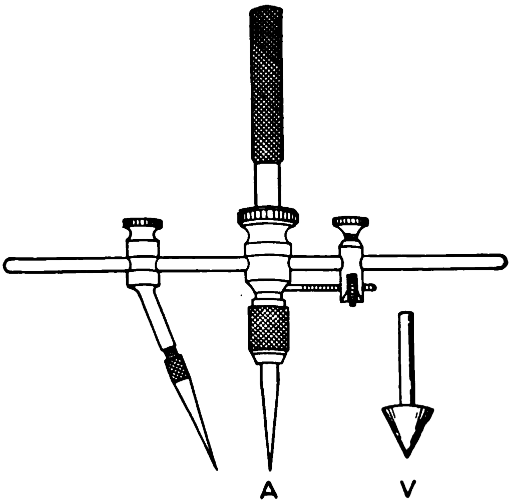


Fig. 62.

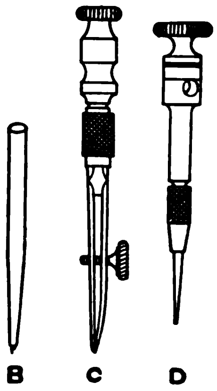


Fig. 62A.

Inside calipers for taking inside dimensions and inside distances are shown in Fig. 65.

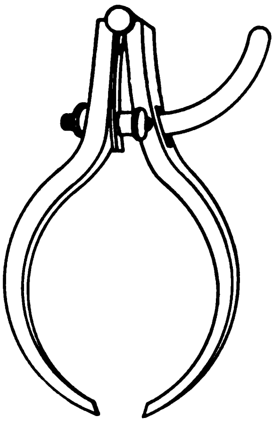


Fig. 63.

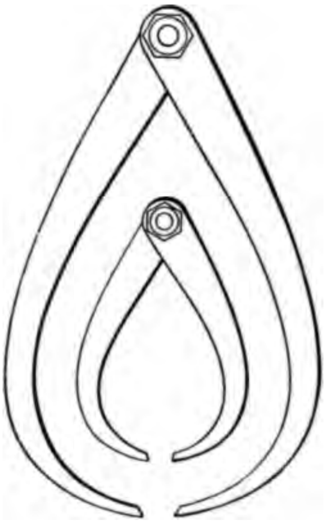


Fig. 64.

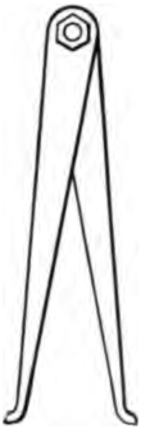


Fig. 65.

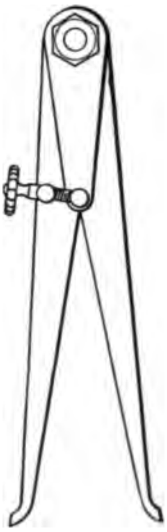


Fig. 66.

The adjustable inside calipers are illustrated in Fig. 66.

Calipers are used for measuring the distances between points external and internal, when a rule could not be used with accuracy.

They are indispensable to the wood turner for measuring the diameters of cylindrical forms and other work while being turned to required dimensions in the lathe. When used by the pattern maker, they may be applied while the wood is revolving, until it has been reduced almost to the required dimensions; after which, when the calipers are used, the lathe should be stopped, to prevent the surface from being marked by the points, and in order to obtain exact measurements.

The calipers should not be pushed or forced over the piece, but in passing over the finished cylinder, the points should touch it lightly without springing the legs of the calipers; otherwise the required dimensions cannot be obtained with accuracy.

MISCELLANEOUS TOOLS.

There remain to be described a few tools, which, while necessary, are so common as hardly to require either illustration or description. Among these are the **hammer,** the best form of which for the pattern maker is shown in Fig. 67, and the **mallet,** of which the best form is shown in Fig. 68.

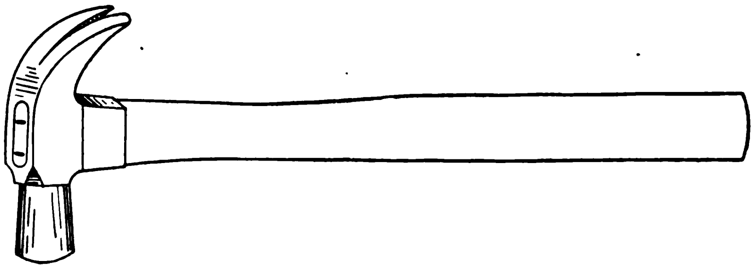


Fig. 67.

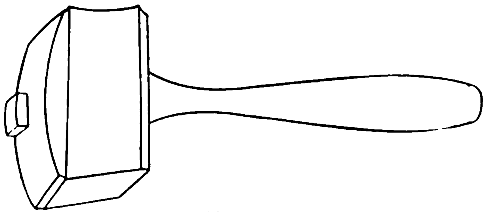
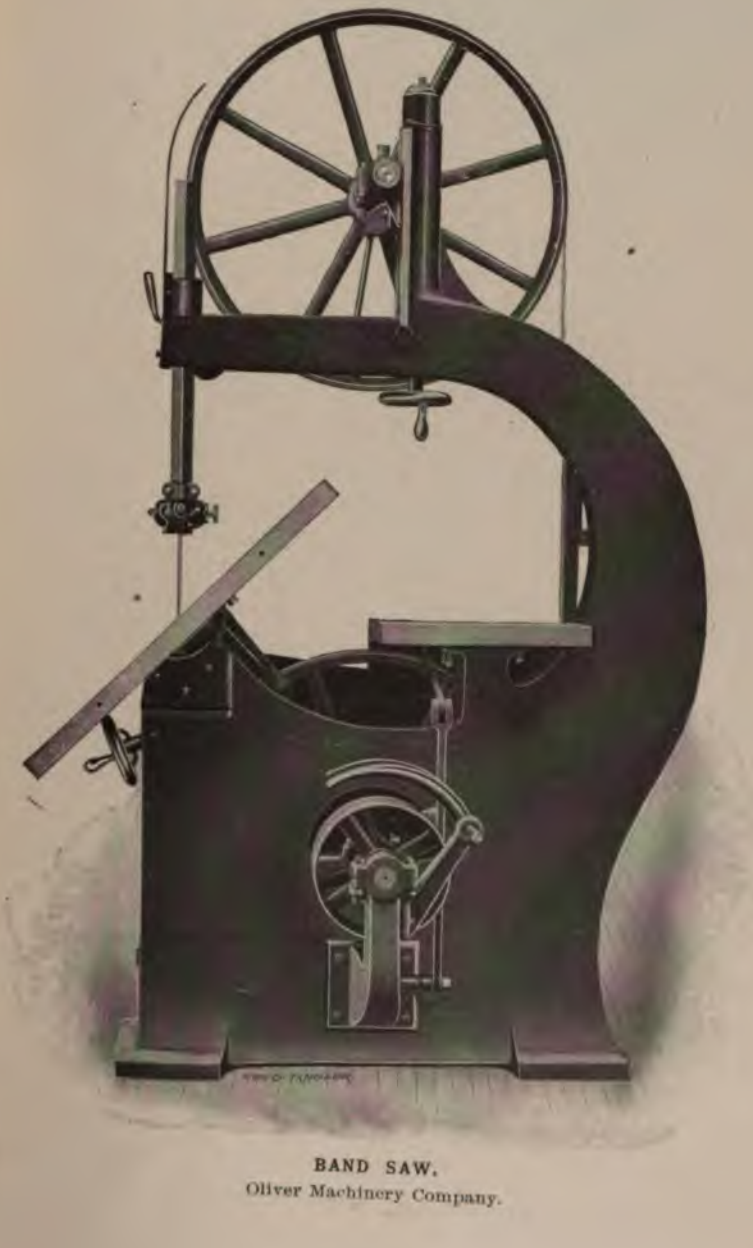


Fig. 68.

A mallet that is to be used on the handle of firmer chisels and other pattern maker's tools, should not be made of hickory or of lignum-vitæ, nor have hard-rubber or hard-fibre facing. Mallets thus made soon mar, splinter, and destroy the tool-handles on



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which they are used. Beechwood and maple furnish the best material for mallet-heads for the use of the woodworker who works in pine and other soft woods. It is true that the mallet-head will not last so long if made of beech or maple wood; but the chisel and gouge handles will be protected, which is a matter of much greater importance.

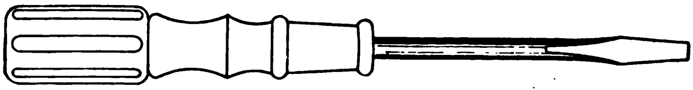


Fig. 69.

Of the **screw-driver,** illustrated in Fig. 69, at least two or three sizes will be found necessary.

The **scratch-awl,** Fig. 70, although used but little at the work-bench (a knife being used in its place for all accurate markings), is indispensable to the pattern maker for laying out the dimensions on his work while it is revolving in the turning lathe. It should be long and slender, as shown, and is used on the revolving wood by placing it over the required graduation of the rule, while the latter is held on the tool rest.

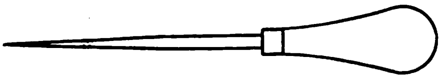


Fig. 70.

Brads and small wire nails must often be driven at such an angle to the grain of the wood, or in such a position, as to make it necessary first to bore a small hole in order to start the brad in the required direction. The brad-awl, illustrated in Fig. 71, is a convenient tool for this purpose. It is commonly ground to a chisel point, as shown at *a*, but will be less liable to cause splitting, and will work faster and with greater ease, if ground to a double spear point, as shown at *b*. The four corners, if kept sharp, will enter the wood and cut faster than the chisel point.

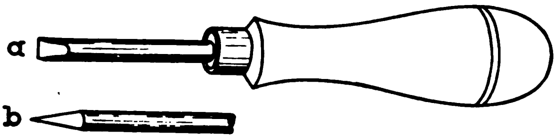


Fig. 71.

Side-cutting **pliers**, such as are illustrated in Fig. 72, will be found convenient not only for cutting off wire and brads, but for removing small brads and for holding small pieces while being worked to shape.

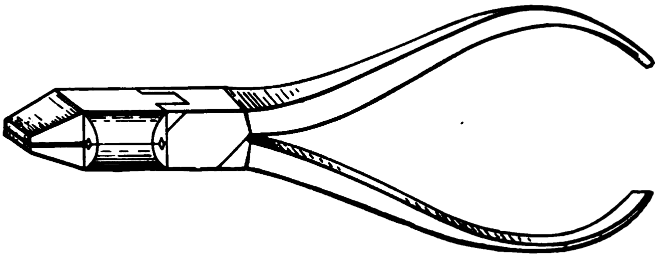


Fig. 72.

Among the tools which cannot be dispensed with are the **brace** and an assortment of **boring bits.** The most desirable style of brace is the **ratchet brace,** illustrated in Fig. 73. The convenience of the ratchet will soon be apparent from the necessity, so often arising, for boring holes or driving screws (with the brace) in angles or close to projections where the full sweep of the brace cannot be taken. Braces are made in many sizes, with sweep varying from 6 inches to 14 inches in diameter.

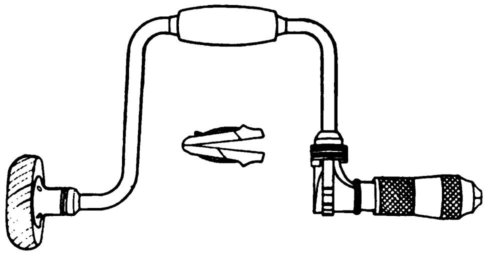


Fig. 73.

A brace with an 8-inch sweep is the most convenient in size for boring holes one inch or less in diameter in soft wood. For larger holes, and especially in very hard woods, a 10-inch or 12-inch sweep will be necessary.

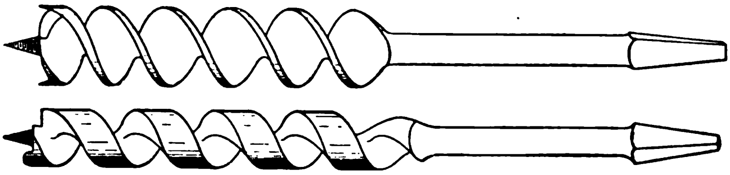


Fig. 74.

Wood-boring bits are made in many styles. The most important are the auger bits, two styles of which are shown in Fig. 74.

They can be bought in sizes running by sixteenths of an inch from $\frac{1}{4}$ inch to 1 inch. For holes larger than one inch, the **No. 2 extension bit,** shown in Fig. 75, is the best. It has two cutters, and will bore a hole of any size from $\frac{7}{8}$ inch to 3 inches in diameter.

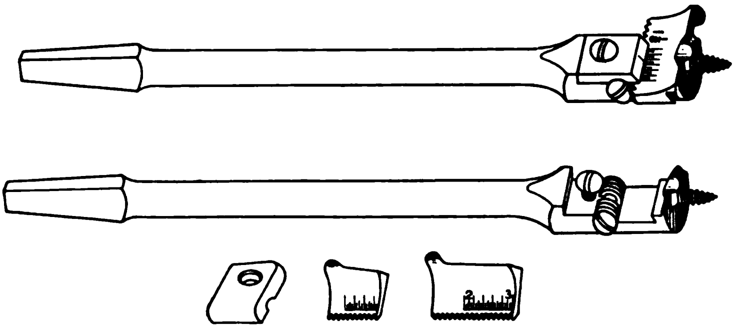


Fig. 75.

For screw-holes, the **gimlet bit** or the **twist drill** for wood, both of which are illustrated in Fig. 76, can be bought in all sizes running by thirty-seconds of an inch from $\frac{1}{32}$ inch up to $\frac{3}{8}$ inch.

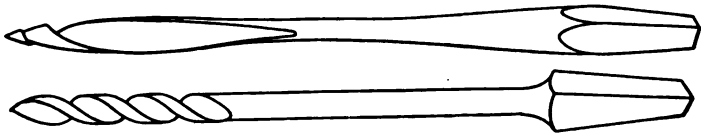


Fig. 76.

The **brace screw-driver,** and also the **brace countersink** for screw-heads, are important tools. They are shown in Fig. 77, and can be bought in large, medium, and small sizes.

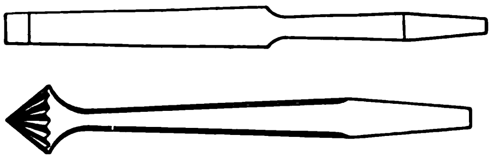


Fig. 77.

The half-round **cabinet file** and half-round **cabinet rasp,** shown in Fig. 78, enter largely into the work of the pattern maker, and should be bought in sizes each of 6 inches, 8 inches, and 10 inches. Larger as well as intermediate sizes may often be found necessary, but will not be needed for ordinary work.

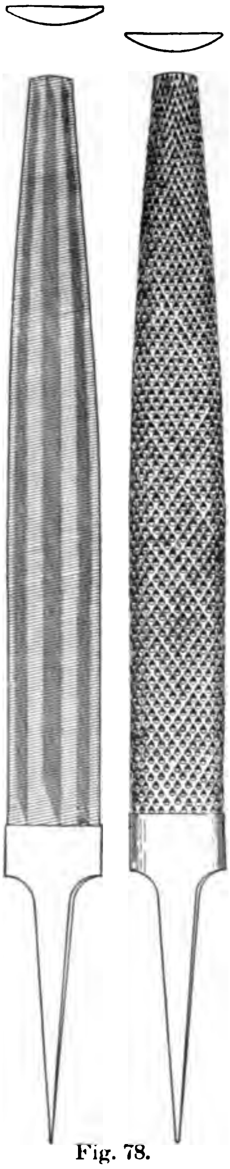


Fig. 78.

Every pattern shop should have at least one dozen each of three or four different sizes of **hand-screws** or **clamps** similar to that shown in Fig. 79. These are adjustable through wide ranges. They are used for clamping together the material that is being glued up to form the different parts of a pattern, and are convenient also for many other purposes. The all-iron C clamp, shown in Fig. 80, is sometimes useful in positions that are hard to reach with a hand-screw. The method of adjusting and of using the hand-screw will be fully explained later.

RULES.

For all ordinary measurements, a 2-foot, folding **standard rule,** Fig. 81, will be sufficient, but this rule must not be used for laying out or for working patterns, or any part of a pattern or core box, to the required dimensions. For all such purposes a **shrinkage rule** must be used. The reasons are that when a mould made from the wooden pattern in the sand is filled with molten metal, its temperature is very high, and as it cools and solidifies it contracts. Accordingly, to compensate for this, the pattern maker must add to the size of the pattern. In order that this may be done, and exact relations nevertheless be maintained for all dimensions, a shrinkage rule is used. This rule is marked off exactly like an ordinary rule; but if the two are compared, the shrinkage rule will be found to be about $\frac{1}{8}$ inch longer than the other for each foot of length.

The contraction or shrinkage of different metals in the moulds varies greatly, that for cast iron being, as above stated, $\frac{1}{8}$ inch to each foot. For brass, however, the shrinkage is $\frac{3}{16}$ inch to the foot; and for many of the softer metals it is as great as ¼ inch per foot. Shrinkage rules, Fig. 82, are usually made of a single piece of boxwood or beech, those for cast iron being 24¼ inches long, for brass 24⅜ inches long, and for other soft metals 24½ inches in length. They can also be bought made of tempered steel 12⅛ inches, 12$\frac{3}{16}$ inches, and 12¼ inches in length. In making use of the shrinkage rule, the workman will proceed just as though

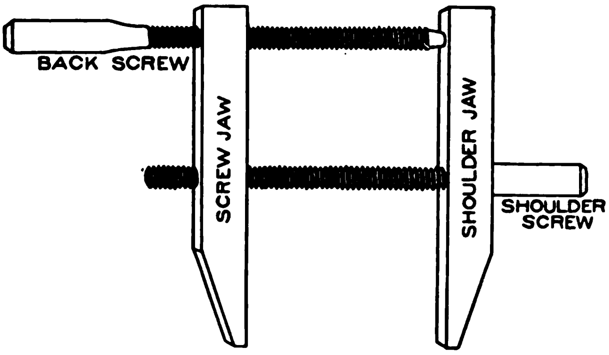


Fig. 79.

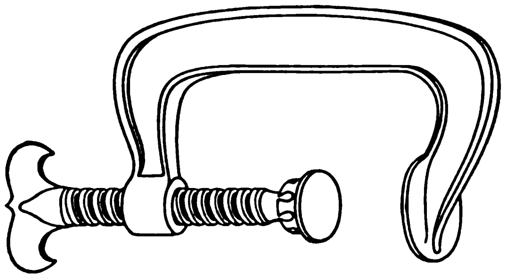


Fig. 80.

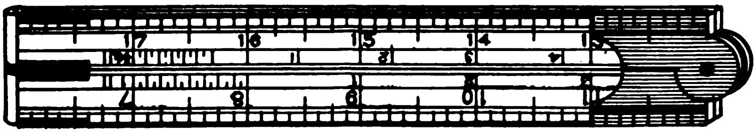


Fig. 81.

he were using a standard rule; and when the pattern is completed it will be found to be larger in all its dimensions, just in proportion as the extra length of the shrinkage rule makes it greater than the standard rule

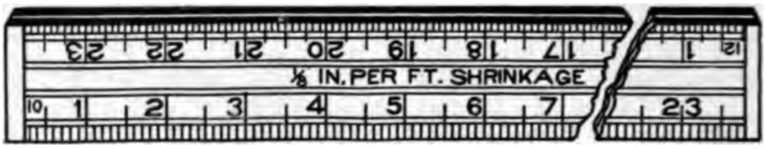


Fig. 82.

OIL STONES.

As before stated, new planes, chisels, and other edged tools, if of the best quality, are always sold ground and sharpened, ready for use. When used, however, they soon become dulled, and must then be resharpened, and be so kept as to have a smooth, keen cutting edge, in order to do good work and to work rapidly. The method employed for doing this is the same for all edged tools, whether ground and sharpened on one side or on both sides.

Oil stones are used for plane-irons, chisels, and all flat and straight-edged tools; and **oil slips**, having rounded edges, for gouges, and for all tools having curved edges. They are made of different sizes, and may be found of many and widely different qualities. The best known and most widely used oil stones in this country, and perhaps in the world, are the "Washita," of which the "Lily White Washita" brand, being carefully selected, are the most even in grade and quality, and are the best-adapted natural stone for woodworkers' tools.

The Arkansas oil stones are claimed to be the hardest and finest oil stones in the world. They are composed of nearly pure silica in the form of minute crystals interpenetrating one another, and differ from the Washita only in the minuteness of the crystals and in their more compact arrangement. They are consequently very much harder and cut hardened steel more slowly than coarser grades of stone, but impart a finer and smoother edge to the tool. They are used by wood-carvers, engravers, watchmakers, and others using tools that require a very fine edge or point. They are expensive, and should be used carefully with equal parts of sperm oil and glycerine.

For wood turners' and pattern makers' tools, the sharpening qualities of the "Washita" are unsurpassed; but the quality differs greatly in stones sold under this name, some being uneven in hardness, and some soft and worthless. No trouble will be found, however, if some good selected brand such as the one mentioned above is chosen. A good size for an oil stone is 6 inches to 8 inches in length, and from 1⅝ inches to 2 inches in width. The thickness does not matter, but the stones usually vary from ¾ inch to 1¼ inches in thickness.

The oil slip should be about 4½ inches in length, and from 1¾ inches to 2 inches in width, tapering from ⅝ inch on one edge to 3/16 inch on the other, both edges being rounded as shown in Fig. 83.

In using the oil stone, care should be taken to *hold the bevel of the tool flat, or nearly flat, on the stone*, so that the cutting edge may be kept thin and in easy working condition. The stone is held stationary on the work-bench, and the tool is moved forward and backward over its face. In the use of the oil slip, on the other hand, the tool is held stationary, with the cutting edge or end up, and the slip is rubbed over the beveled surface with a circular motion or stroke, until a keen, sharp edge has again been imparted to it. An abundance of oil should always be used in order that a finer and smoother edge may be given to the tool, and the pores of the stone be kept clean and free from glazing.

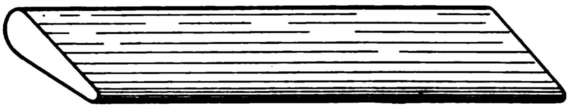


Fig. 83.

In the last few years an entirely new variety of oil stone and oil slip has been placed on the market. It is called the **India oil stone,** and is made from corundum, the hardest of all mineral substances except the diamond. These stones have wonderful cutting qualities, and differ greatly from other oil stones in that they cut steel much faster, impart better edges, and do not glaze. They are also of uniform texture throughout. India oil stones are furnished in three grades—coarse, medium, and fine—and in all required shapes, a few of which are shown in Fig. 84. Only the "fine" stones are adapted for woodworking tools and for those classes of tools requiring a fine cutting edge.

GRINDSTONES.

Second in importance to a good oil stone is the grindstone, power-driven if possible. It should not be too close-grained. A rapid-cutting stone, even if moderately coarse, is greatly to be preferred, as all ground edges must be finished on the oil stone however finely they may have been ground on the grindstone.

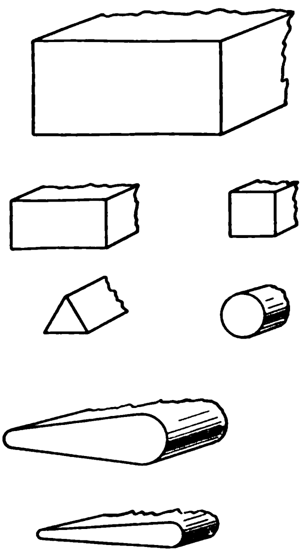


Fig. 84.

A stone about 36 inches in diameter when new, is a good size; and can be bought with a suitable cast-iron trough underneath, and also with an arrangement for supplying the water necessary to keep the stone wet.

In all stones there will be found great differences of hardness in different parts. Stones soon lose their cylindrical shape and must be turned true. A piece of gas-pipe or an old file will be found excellent tools for this purpose, but they must be used without water.

In using the grindstone for plane-irons, chisels, and other tools that must be ground with a long bevel, or to a thin edge, it is better to stand so that the stone runs toward the cutting edge of the tool, as shown in Fig. 85. This position grinds the tool much faster, and less of a feather will be turned up on the final edge.

Scraping tools, however, and indeed all tools having a very short bevel, or whose edges are ground to a very obtuse angle, may be held so that the stone will revolve away from the cutting edge of the tool, this position being less liable to cut hollows in the face of the stone. This method of grinding, however, is too slow for tools having a long bevel, and which for that reason require more grinding.

When to use the grindstone is a question that often occurs to the beginner, who sometimes confuses the use of the grindstone with that of the oil stone. The grindstone is not in any sense an instrument for *sharpening* woodworkers' tools. When a chisel or a plane-iron has been sharpened on the oil stone for several successive times, the bevel is gradually worn shorter, and its shape changed from that shown at *a*, Fig. 86, to a shape similar to that shown at *b*. When the length of the bevel is thus reduced, the angle of the cutting edge is too obtuse to do good work, or to work easily. The metal at *c* must then be ground off on the grindstone, and the bevel of the tool restored to its former correct shape as shown at *a*, after which the cutting edge must be sharpened and finished on the oil stone.

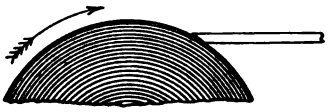


Fig. 85.

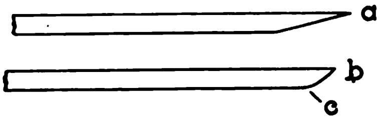


Fig. 86.

LATHES.

Of all power-driven machines, the most indispensable to the pattern maker is the **wood turning lathe.** In a small shop where small patterns only are made, a 14-inch or a 16-inch speed lathe, such as is shown in Fig. 87, may prove sufficient for all purposes; but if only one lathe can be afforded, it should be a regular pattern-maker's lathe, similar to that illustrated in Fig. 88.

The latter differs from the speed lathe in that the head-stock spindle extends through the left-hand bearing, and is fitted to receive face-plates and chucks, the same as on the inside end.

The arrangement of the countershaft is also such as to give a much wider range of speed to the lathe head, so that pieces of very large diameter may be turned at a speed proportioned to their sizes. These lathes are also fitted with a hand-feed slide rest —either compound, as shown in the illustration, or a plain sliding tool-holder moved by a rack and pinion, as may be desired. The tail stock is so arranged as to be adjustable for turning long cylinders, either tapering or straight, as may be required. When not in use the slide rest may be removed from the lathe, and the ordinary tool rest and rest socket substituted in its place for hand turning.

The speed at which a lathe should be run is always indicated by the manufacturer, the countershaft usually running at a speed of 500 to 550 revolutions per minute.

A variety of **chucks** and **face-plates**, used for holding the work, are always furnished with a lathe. Some of these are shown in the engraving, the screw chuck being shown at *a*, Fig. 88; and two of the iron face-plates are shown, one on each end of the spindle.

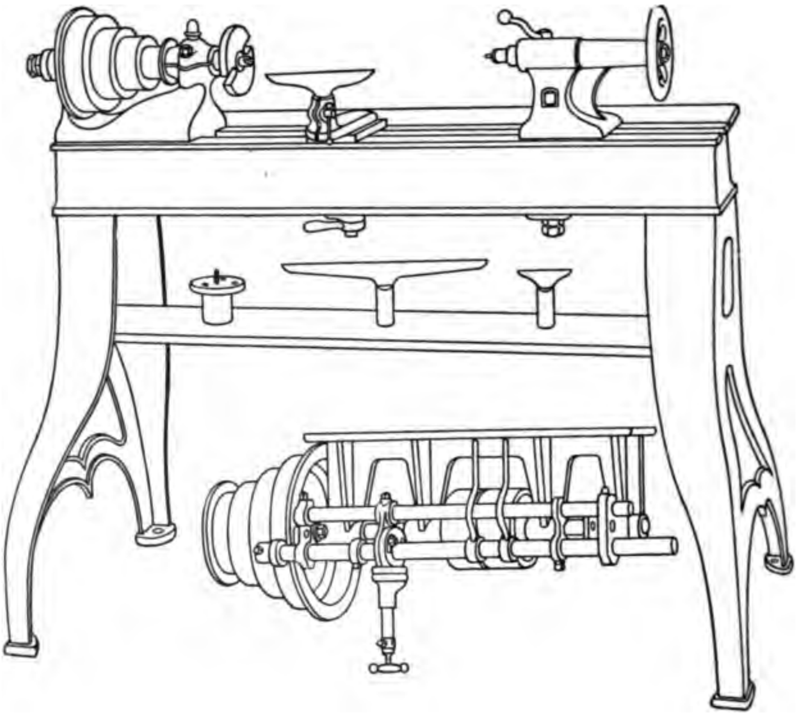


Fig. 87.

But in addition to these face-plates, which really form the base only for chucking the pattern, **wooden chucks** must be used intermediate between the iron face-plate and the pattern. These wooden face-plates are constructed in a variety of ways by different pattern makers; but for small patterns it is necessary to use only a plain board ⅞ inch to 1¼ inches in thickness and of a slightly greater diameter than the required pattern. This board is screwed fast to the iron face-plate as shown in Fig. 89, to which, after being placed in the lathe and turned true, the pattern is attached, as will be fully illustrated and described farther on. For patterns of a medium size, say 20 inches to 30 inches in diameter, the board should be stiffened by means of a wide wooden bar firmly screwed across the back, as in Fig. 90.

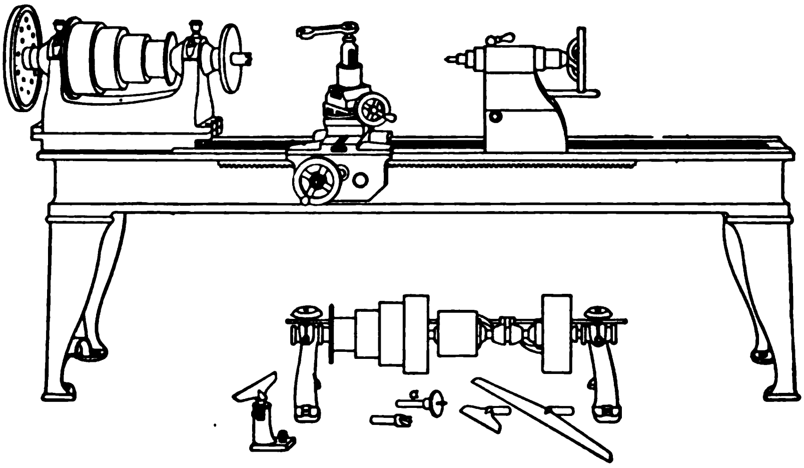


Fig. 88.

When chucks are needed for very large or heavy work, the chuck, in order to prevent vibration, must be strong in proportion. It is best made as illustrated in Fig. 91, in which the front of the chuck, as shown at *a*, will be least affected by the moisture in the air if left unglued, or at best only tongued and grooved, being held together by the cross-bars only, as shown at *b*, to which it is firmly screwed, without glue. This chuck is simple and cheap, and will be found in practice much stronger and more rigid than one built up out of sectors or in a more elaborate way.

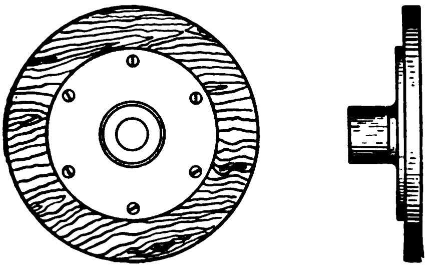


Fig. 89.

LATHE TOOLS.

Of lathe hand tools the first to be considered, as also the first to be used, is the **gouge.** It is used for reducing the stock to be turned, from a rough or rectangular shape to a cylindrical form, preparatory to smoothing and finishing. It is ground and beveled on the back or convex side, and the shape of the cutting edge should be of the same curvature as the inside, or upper side, of the tool. Gouges are made in all sizes, one of which is illustrated in Fig. 92; but for the pattern maker's use four gouges, ranging from ¼ inch to 1¼ inches, will be found sufficient for all purposes.

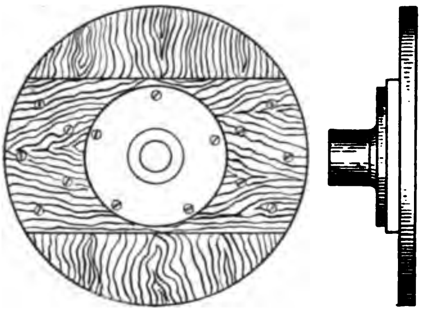
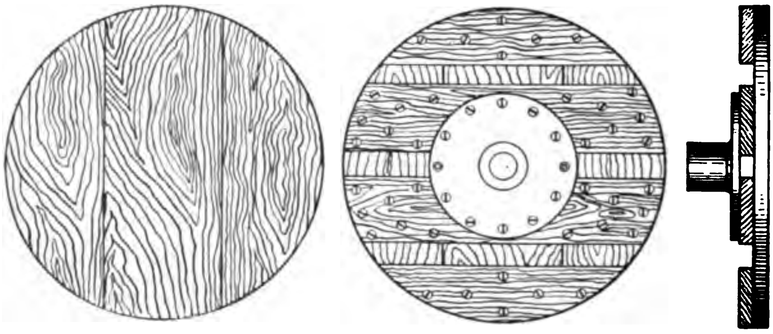


Fig. 90.

Before using the gouge, and indeed any lathe-cutting tool, the workman should take care to see that the tool rest has been elevated above the center line of the lathe centers, from ¼ inch for small work to 1 inch or more for large work. The position of the gouge, when in use, is horizontal and at about a right angle to the tool rest. It should not, however, be laid on the rest so as to use only the extreme point of the tool, but should be tilted over, first to one side and then to the other, so as to bring all parts of the cutting edge, successively, in contact with the wood that is being turned.



a Fig. 91. *b*

The gouge may be used by the beginner without hesitation, as in no position, whether tilted or on its back, will it catch or rip into the wood. The tool should be held firmly by the extreme end of the handle, in the right hand, while the left hand rests against the tool rest, the blade of the tool being grasped lightly with the fingers, and passing through and under the left hand while resting on the tool rest.

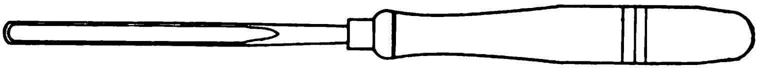


Fig. 92.

The turning gouge, being curved, can be used only as a roughing-down tool or for turning out hollows, and cannot be used for finishing. It will not make a straight, true, or smooth surface. For this purpose, in common and ornamental turning, the **skew chisel,** one size of which is shown in Fig. 93, is used. This form of chisel is made in all sizes from ⅛ inch to 2½ inches in width, but, unlike the gouge, requires considerable practice and skill for its successful use.

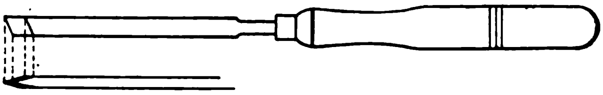


Fig. 93.

The skew chisel is held slightly tilted so that while the short edge of the blade touches the tool rest, the long edge will be slightly above the rest, so that the long corner of the skew point extends *up* and well *over* the cylinder which is being smoothed, thus preventing the long skew point from catching and tearing into the work. All the cutting must be done with the short part of the skew edge, say one-half inch only of the cutting edge, the tool resting not only on the tool rest, but resting also firmly on the cylinder that is being turned, just as a plane rests on a board while cutting and removing the shavings from its surface. The right position for this tool is hard to obtain at first, and can be acquired only by patient and continued practice. In no case, however, should the skew chisel be held *flat* on the tool rest, or used as a scraper, this not being allowable or good practice easily and quickly be raised to a cutting position. The front half of the table is made to slide, while the whole table can be tilted to an angle of 45°, and will remain in any position desired without clamping. As shown, it is provided with adjustable gages for crosscutting or mitering, and with an adjustable fence for ripping, all of which are removable at will, leaving the whole upper surface of the table clear. Fig. 97 gives a view of the table from above. As in the case of the turning lathe, the intended speed of the saw countershaft is indicated by the manufacturer.

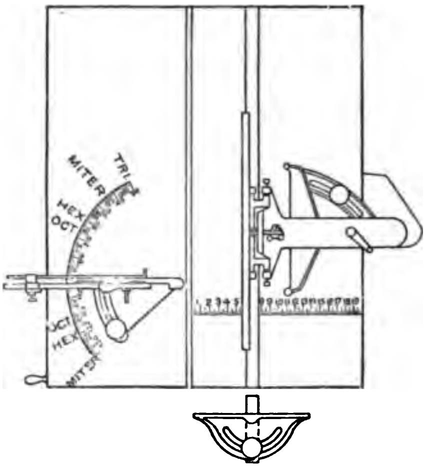


Fig. 97.

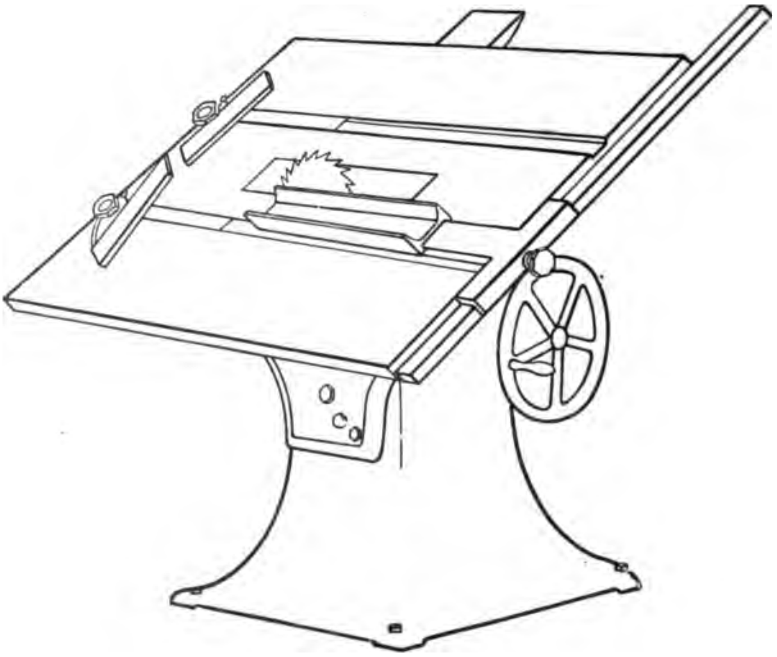
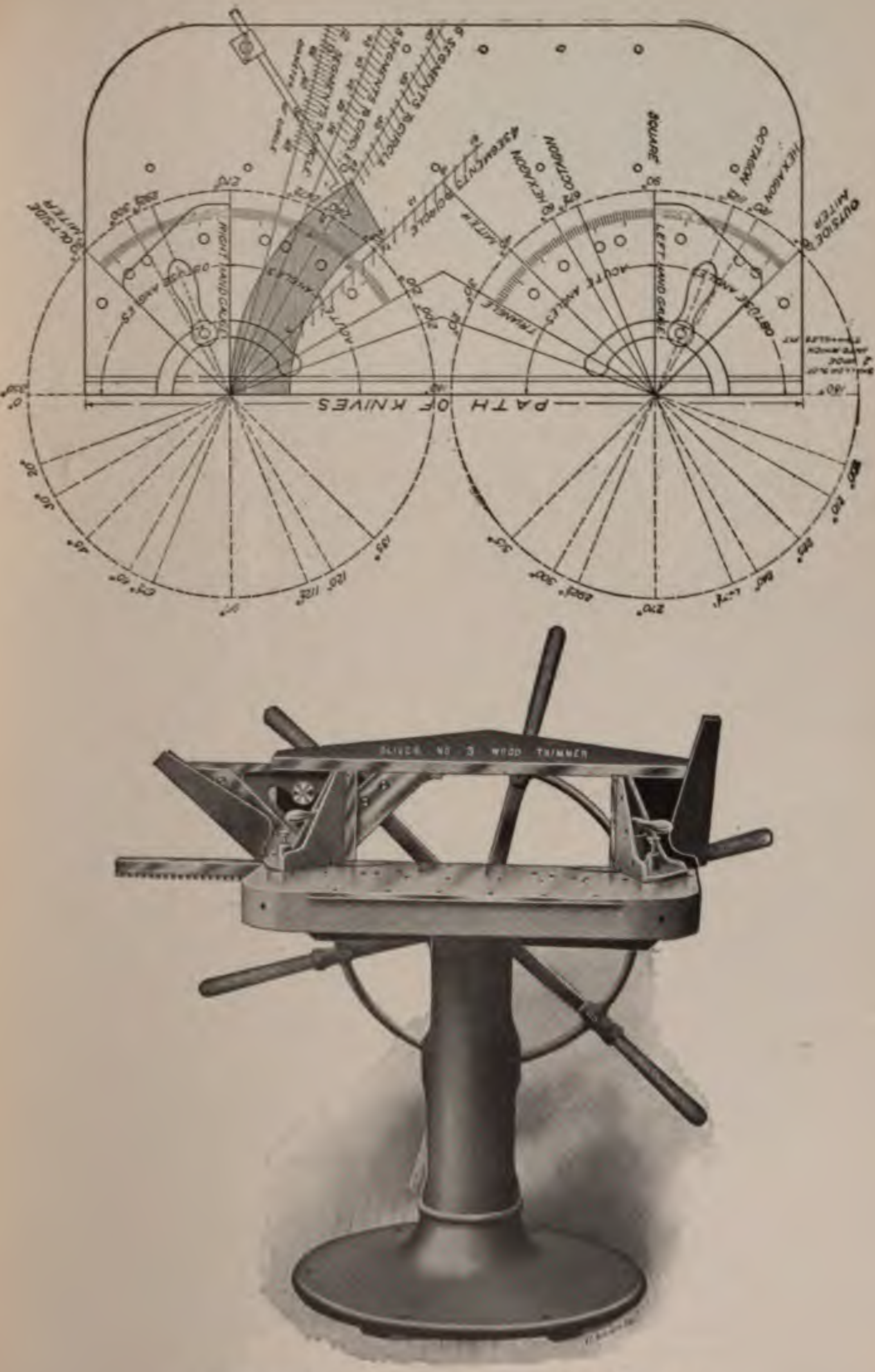


Fig. 98.



UNIVERSAL TRIMMER, SHOWING GRADUATIONS.
Oliver Machinery Company.

The single-arbor circular saw bench shown in Fig. 98 is a less expensive machine than that just described; but the time lost in having continually to change the saw on the single arbor from rip to crosscut and back again for pattern work, is a very annoying as well as expensive inconvenience.

BAND AND SCROLL SAWS.

A good **band saw,** such as the one illustrated in Fig. 99, is indispensable for cutting the curves and irregular shapes that form a part of so many patterns. The best machines of this description have a tilting table which can be set and clamped at any angle, enabling the workman to give the required level or draft to his work.

With a sharp and well kept saw, there is no more rapid or correct method of cutting out and making circular core boxes of all sizes whose length is within the capacity of the machine. The block from which the core box is to be made must be cut perfectly square on the end that is to rest on the saw table; and, if this end of the block is not large enough to give sufficient base to hold it in an upright position, the block can be supported against the blade of a try-square, or, better still, against a wooden bracket made for the purpose.

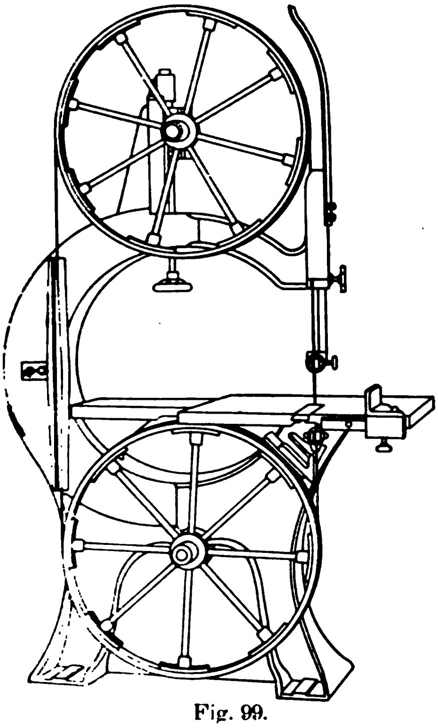


Fig. 99.

The **scroll saw,** illustrated in Fig. 100, is necessary for cutting inside curves and openings in which a band saw could not be used. Like the band saw it should have a tilting table. Where both saws cannot be afforded, the scroll saw will take the place of both.

While not working so rapidly as the continuously cutting blade of the band saw, it is, when kept sharp and in good running condition, a great time- and labor-saving machine.

PLANING MACHINES.

Because of the fact that pattern lumber can be bought already dressed to any required thickness, a planing machine is not found in every pattern shop. The ordinary surface planer, however, will not take the twist, or wind (*i* as in *find*), and the curves out of the surface of the lumber —a matter of very great importance in pattern work, and one which requires a great deal of time if the planing is done by hand.

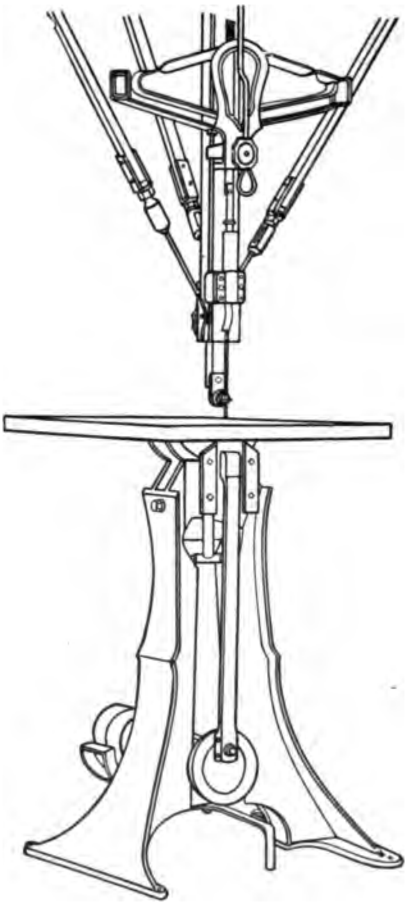


Fig. 100.

The **hand planer and jointer,** illustrated in Fig. 101, is almost indispensable, not only for facing the sides of boards perfectly true, straight, and free from wind, but also for jointing the edges, and for making perfectly-fitting glue joints in a manner superior to any hand work. These machines can be bought in widths of from twelve to thirty inches. A machine sixteen inches wide is a very desirable size for pattern work.

It will readily be seen that the running of a board over the hand planer, while facing the surface straight and true, will not reduce the piece to a uniform thickness. To avoid the necessity for much hand work in accomplishing this result, first face the piece on the hand planer so as to make one true side, and then run it through a surface planer similar to the one illustrated in Fig. 102. If they can be afforded, both of these machines (especially the hand planer) will return large profits on the money invested in them, because of the time and labor saved and the superior quality of the work done.

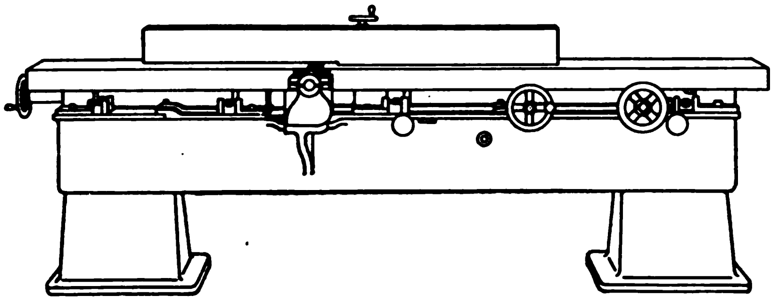


Fig. 101.

Among the many labor-saving tools of late years, there is perhaps none more popular and none more indispensable in a pattern shop than the **universal wood trimmer.** It will cut any end or angle within the capacity of the machine; and an end which would take from ten to fifteen minutes to square and true up

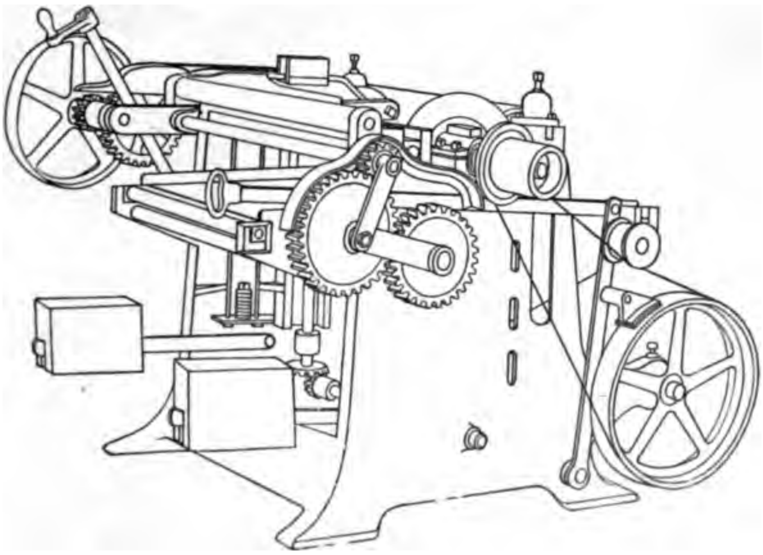


Fig. 102.

correctly by hand with square and plane or chisel, can be finished in as many seconds with this tool. It is made in many sizes, from the small bench trimmer, two views of which are shown in Fig. 103, to the large machine illustrated in Fig. 104. The former will cut 6 inches wide and 3 inches high. The larger machine will cut 20½ inches wide and to a height of 7½ inches.

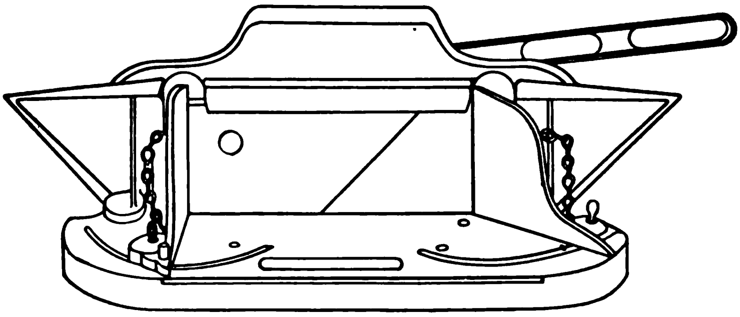


Fig. 103—Front View.

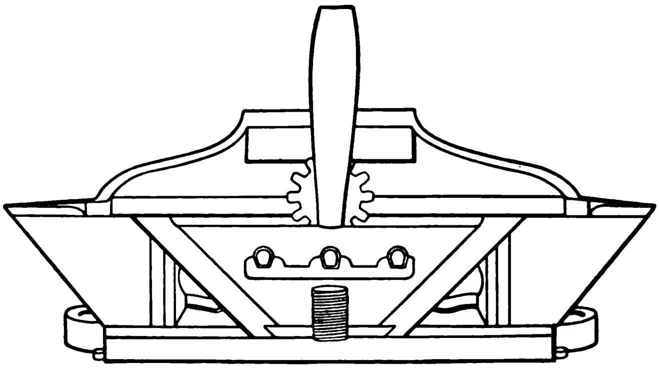


Fig. 103—Rear View.

The small No. 0 machine, shown in Fig. 103, is so comparatively inexpensive, and the time it will save so great, to say nothing of the quality of the work produced, that it should be on the bench of every pattern maker. These machines will cut the acute angles between 45° and 90°, and the obtuse angles between 90° and 135°.

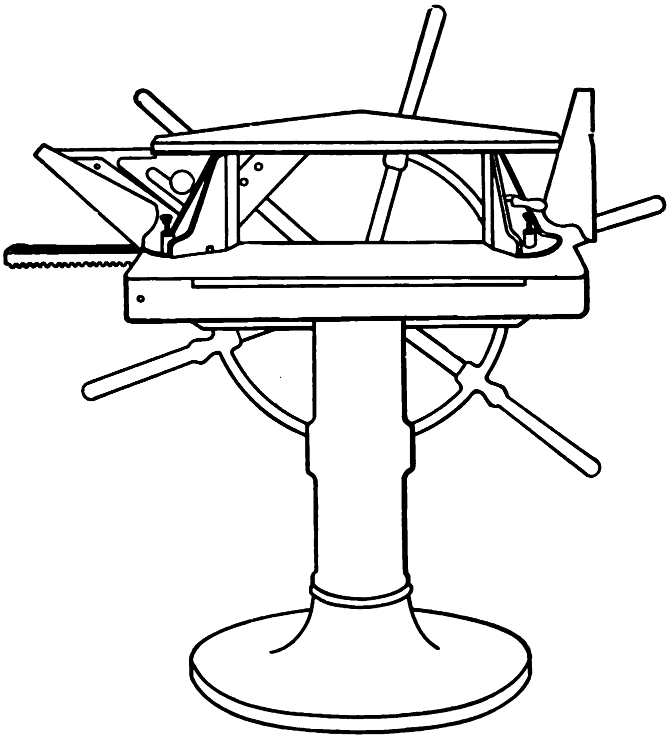


Fig. 104.

METHODS OF MOULDING.

As has already been said, it is necessary that the patternmaker should have some knowledge of moulding in order that he may construct his patterns so that they can easily be removed from the sand. A brief description of the general method employed will suffice.

Ordinarily, a casting is made in a **flask** consisting of two parts, each containing its complement of sand. The upper part is called the **cope,** and the lower part the **nowell** or **drag.** The pattern is sometimes made in two pieces that *part* along the line separating the cope and the drag. Thus in Fig. 105 the pattern separates with the flask, on the line A B; and when so separated, the cope is turned upside down and the portion of the pattern C is lifted out. The part D is lifted out of the drag in the same way.

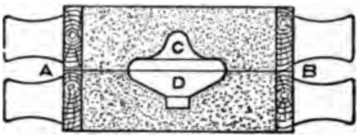


Fig. 105.

In the case of moulding a hollow object, the internal cavity in the casting is formed by means of a dry sand **core**, which rests in impressions made in the sand by **core prints** attached to, and forming a part of, the pattern. To illustrate this, let it be required to cast the hollow cylinder shown in Fig. 106. The wooden pattern necessary to produce this hollow cylinder is shown in Fig. 107, which, as will be seen, represents the cylinder only externally by the part A.

The core prints, one on each end of A, are represented by *x* and *y*. These projections form part of the pattern, and make their impressions in the sand with the part A, which alone represents box will be the extreme length of the pattern including *x* and *y*, and the inside width will be the exact diameter of the core prints. In this case, the core being a cylinder, only a half core box (Fig. 108) is used. In it are made two semi-cylindrical cores, which, after being dried, are cemented together, thus forming the complete cylindrical core required.

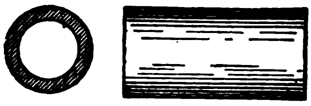


Fig. 106.

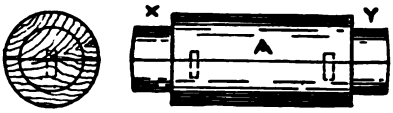


Fig. 107.

To mould this halved or *partea* pattern as it is called, the upper half of the pattern is laid on the moulding board, and the *drag* is turned over it with the bottom side of the drag up and the parting side on the moulding board, as shown in Fig. 109. After being "rammed up," the drag and moulding board are turned over and the board removed, when the parting of the pattern will be exposed, the half pattern being imbedded in the sand.

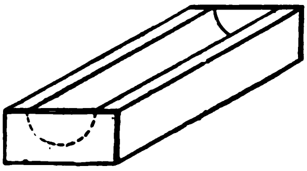


Fig. 108.

The second half of the pattern is now placed in position on the first, and dry parting sand is spread over the surface of the wet or "green" sand; the cope is put in position on the drag, as shown in Fig. 110, and rammed up. Upon the cope and the drag being separated, the sand will separate on the line to which the parting sand has been applied, which, as will be seen, is the line of parting of the cope and the drag, one half of the pattern remaining in each.

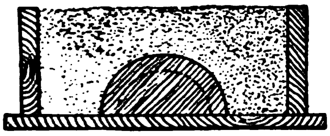


Fig. 109.

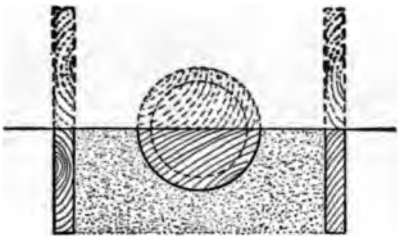


Fig. 110.

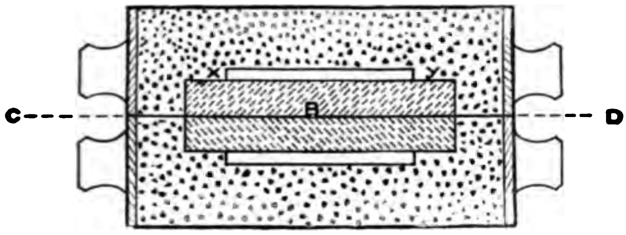


Fig. 111.

After the pattern has been removed (one half from the cope. and the other half from the drag), the completed dry sand core is placed in the moulds made by the core prints *x* and *y*. This core B is shown in position in Fig. 111 and entirely fills the parts of the mould made by *x* and *y*, leaving between itself and the surface of the mould made by A, room for the metal to be poured which is to form the required cylinder.

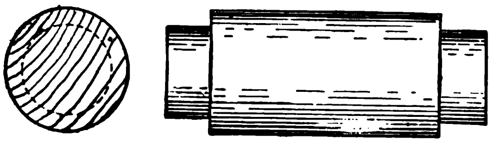


Fig. 112.

In moulding the above cylinder it is not necessary that the pattern should be parted (made in two halves) as shown in Fig.

107. Patterns for small work, and even for large castings, are often made in one piece, as shown in Fig. 112. To mould this solid pattern it is placed on the moulding board with sufficient sand to keep it from rolling, and the drag is inverted over it as before. When the drag has been rammed up, it is turned over, and will then present the appearance shown in Fig. 113, the entire pattern being embedded in the sand. The sand is now cut away and removed, as shown in Fig. 114, down to the center line of the pattern. The cut sand is smoothed; and, after dry parting sand has been applied to the surface of the wet sand, the cope is placed in position and rammed up as usual.

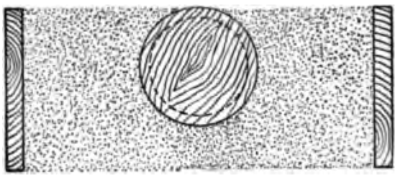


Fig. 113.

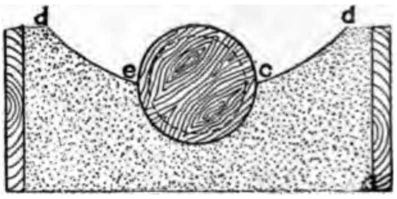


Fig. 114.

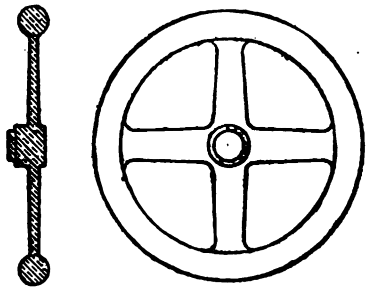


Fig. 115.

Upon the cope being removed, the sand will part along the lines *d e* and *c d*, leaving one-half of the entire pattern exposed. The pattern can now be lifted out, the core placed in position, and the cope returned to its place on the drag, when it is ready for the pouring, as in Fig. 111.

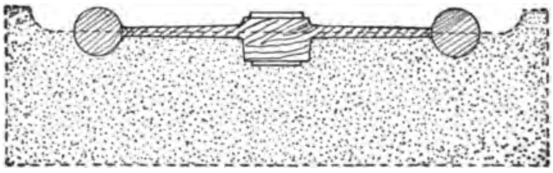


Fig. 116.

Another example of a one-piece pattern is the small brass hand wheel shown in Fig. 115. The pattern for this wheel is placed on the moulding board, and the drag inverted over it and rammed up. After the drag has been turned over, the sand is cut away and removed, not only down to the center of the rim, but also to the center line of the four arms, as shown by the dotted lines in Fig. 116.

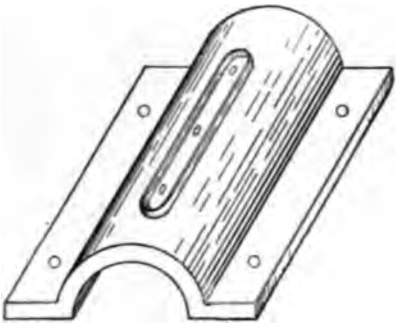


Fig. 117.

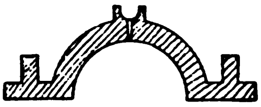


Fig. 118.

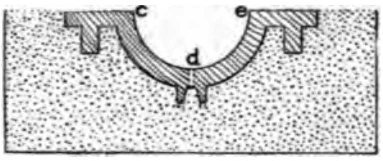


Fig. 119.

All cut surfaces of the sand are smoothed, parting sand is sprinkled over the parting thus made, and the cope is placed in position and rammed up. When the cope is lifted off, the sand will part half way down on the arms and rim, allowing the pattern to be taken out with ease.

Still another example in which a single-piece pattern can be used, is shown in the journal-box cap illustrated in Fig. 117. A cross-section of the pattern through two of the bolt-hole core prints is shown in Fig. 118. The pattern is placed on the moulding board in the inverted drag and is rammed up as usual. When the drag is turned over, the position of the pattern in the sand is as shown in cross-section in Fig. 119. The sand that may have entered the curve *c d e* is lifted out, and the necessary "draft" is given to the sand at the two ends of the opening *c d e*, as shown at *a*, Fig. 120. The cope is next placed in position, and when this has been rammed up and lifted off, the sand lying in the curve *c d e*

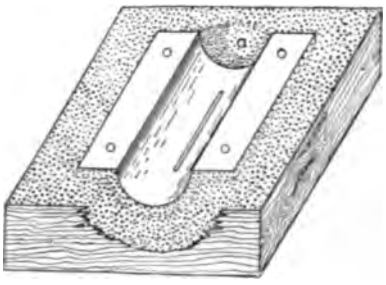


Fig. 120.

will be lifted with it. The pattern is now removed; the bolt-hole cores are placed in position; and the cope is returned to its place on the drag.

In this case the core prints should be in length at least twice the thickness of the metal through which the hole is to be cast, and the length of the cores will be equal to the thickness of the metal plus the length of the prints.

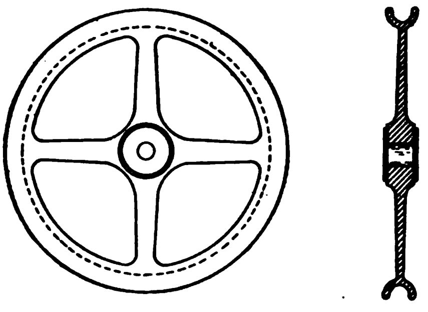


Fig. 121.

In the small sheave pully, Fig. 121, we have an example of a casting the construction of the pattern for which, so as to make it easily removable from the sand, may give some trouble to the beginner. The pattern is shown in cross-section in Fig. 122, and is moulded in a two-part flask. At first it would seem impossible to place the pattern in the sand so that either half could be removed when the cope and drag are separated on the parting line of the pattern. This is readily accomplished, however, as follows:

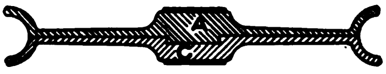


Fig. 122.

The half pattern C is placed in the inverted drag, with the parting downward on the moulding board, and is rammed up in the usual way. After the drag is turned over, the sand is cut away and removed to the center of the rim edge, as shown in Fig. 123. The cut is carefully smoothed, and parting sand applied to the cut surface. The part A of the pattern is placed in position on C, and is rammed up carefully, the sand being then cut away to the center of the rim edge of A. Parting sand is applied to the new surface, after which the cope is placed in position and rammed up.

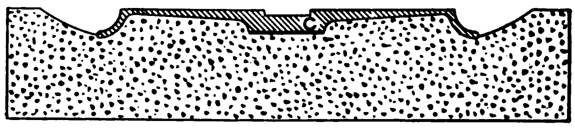


Fig. 123.

When the cope and drag have been separated, the upper half A of the pattern is taken out, and the cope is returned to its place on the drag. The whole flask is now turned over, and the drag lifted off the cope, when the ring of green sand Z, Fig. 124, will rest on the cope sand and the part C of the pattern is taken out. We thus have two partings of the sand mould, but only one parting of the flask.

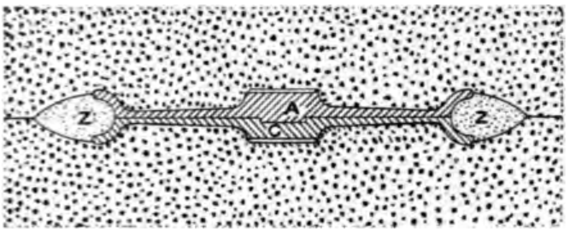


Fig. 124.

Many other examples might be given, as the case of the common two-flange pulley, which, when small, is often moulded in this way.

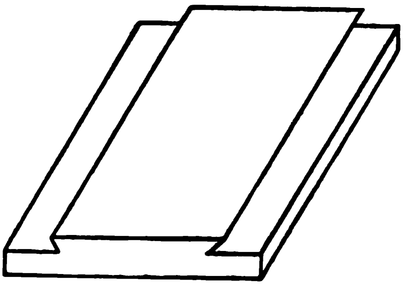


Fig. 125.

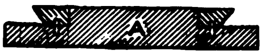


Fig. 126.

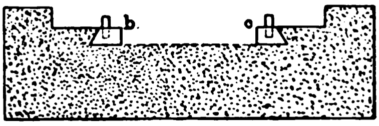


Fig. 127.

It is frequently the case that parts of the pattern will overhang so that the pattern cannot be removed from the sand in any direction, even if parted. In such cases the overhanging parts are fastened loosely to the main part of the pattern by wires or wooden pins. An example of such a casting is shown in the slide, Fig. 125. A cross-section of the pattern for this slide is shown in Fig. 126, in which the two overhanging parts are held in position by the use of pins. After being rammed up, the part A is removed, leaving the parts *b* and *c* still in their positions in the sand, as in Fig. 127. These may now be carefully moved toward the center of the opening and lifted out

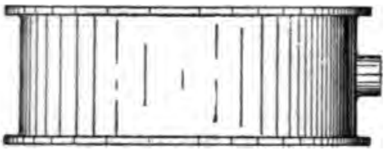


Fig. 128.

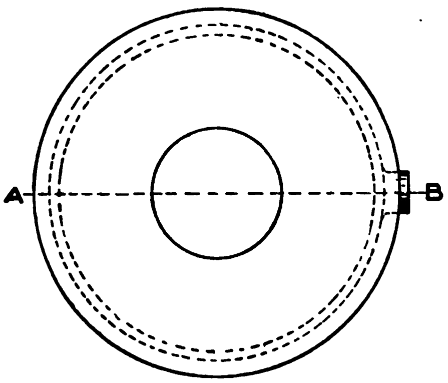


Fig. 129.

In some cases there is not sufficient room, when the main part of the pattern has been taken from the mould, to remove the projecting pieces. In such cases, the overhanging pieces or projections must be made by using dry sand cores. To illustrate this, we shall consider the pattern for the small cast-iron turbine case illustrated in Figs. 128 and 129. A section view of the casting through A B (Fig. 129) is given in Fig. 130.

The pattern is parted on the line C D and will form its own core. The boss *a*, however, will prevent the main part of the pattern from being removed from the sand, and if *a* were made loose it could not be taken out through the narrow space made by the thin side of the pattern. To overcome this difficulty a core print is fitted on the side, extending from the parting line C D to the bottom edge of the pattern, as illustrated in Figs. 131 and 132; and in the impression made by this core print a dry sand core, formed in the core box shown in Fig. 133, is placed. It will readily be seen that this core will, in connection with the pattern, form a mould which will give the casting required.

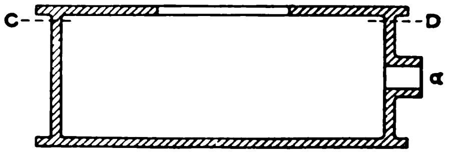


Fig. 130.

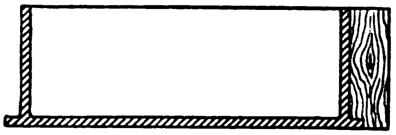


Fig. 131.

Examples in "Methods of Moulding" could be multiplied indefinitely, but the foregoing, we think, will give such suggestions as will enable the beginner in pattern making to construct all

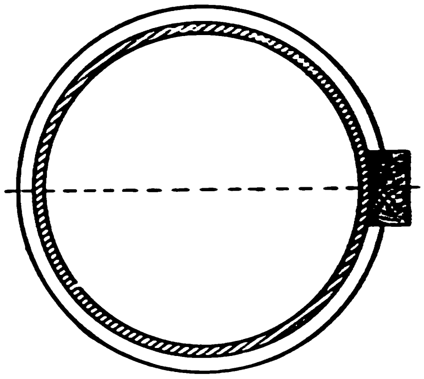


Fig. 132.

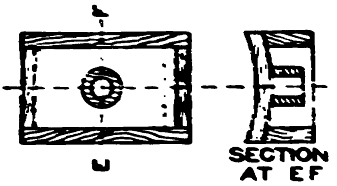


Fig. 133.

ordinary patterns so that they can easily be removed from the sand without injury to the mould.

PATTERNS FROM DRAWINGS.

As already explained, the pattern maker must understand working drawings in order to construct patterns from them directly. These drawings are usually made to a scale much less than the actual size of the required work, and always represent the completed or *finished* machine or one of its parts.

Drawings are made for the machine shop to guide the machinist in cutting, turning, planing, and fitting the parts given, so as to produce in the castings the shapes, sizes, and general requirements of the articles to be constructed. Hence there is less liability for mistakes after the castings reach the machinist, as he has before him not only the drawing with its accurate dimensions to work from, but also the castings for the machine or its parts, from all of which the construction and uses of these several parts can easily be understood.

On the other hand, the pattern maker, with the aid of the same drawing, must *imagine* the casting before him, and must build something in wood which will produce that casting in metal. This pattern, in some cases, will be a duplicate of the required casting, but more often it has only a general resemblance to it, with core prints attached, and is external only, with nothing to show the internal openings, chambers, and winding passages that must be provided for by "coring." The core boxes, in which the cores are to be formed, are not shown in the drawings furnished to the pattern maker, but must be provided by him in correct shapes and sizes, in addition to the pattern itself with its added core prints.

In building a pattern the workman, as before stated, must allow for **shrinkage.** He must also allow for **draft** and for **finish.**

Shrinkage. The shrinkage of cast iron when cooling in the moulds is, as has before been stated, about $\frac{1}{8}$ inch to each foot, and the manner of obtaining the exact sizes for different parts of the pattern has been explained under the head of "Rules" (page 38). For brass or bronze castings a greater allowance must be made, averaging $\frac{3}{16}$ inch to each 12 inches. Shrinkage rules for brass ($\frac{3}{16}$ inch to the foot) can be obtained, and must be used for all patterns made from brass.

Draft. After shrinkage, the second point of importance in a well-made pattern is draft. By this term is meant the bevel or taper made on all vertical parts of the pattern so that it can easily be lifted from the sand without injury to the mould. This is best illustrated as in Fig. 134, in which it will be seen that if the diameter of a pattern at *a* were to be the same as that at *b*, the latter point would drag over the whole length of the sand until it reached the former point. As the sand is held together only very lightly, this dragging would be likely to dislodge some of the particles and make it necessary to mend the mould. In order to avoid this, the diameter at *a* is made slightly greater than at *b*, so that the body of the gland is tapering, and the moment it is started out the whole surface from *a* to *b* is clear of the sand and can be removed without injury thereto. This difference in the diameters at *a* and *b* is called the *draft* of a pattern. The amount of draft depends upon the length of the part that is to be drawn out of the sand.

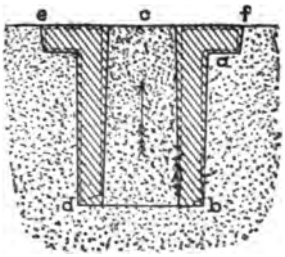


Fig. 134.

The allowance for draft varies with the pattern, and is often greater or less on different parts of the same pattern. For example, the draft on the outside of the pattern of a pulley rim 24 inches in diameter and 6 inches face, should be ⅛ inch to the foot, while on the inside of the rim and on the hub of the pully it should be in the ratio of ⅜ inch to the foot. The reason for this difference is that the face of the rim is often turned and finished *straight*, and for that reason the least possible amount of draft that will allow of the pattern being removed from the sand should be used; while on the inside of the rim a greater amount of draft strengthens the metal rim, which must sustain the strain and pressure of the belt. In general the draft should be from ⅛ inch to ⅜ inch for each 12 inches, the latter amount in all cases where the removal of the metal thus added will not greatly increase the expense of working the casting. To obtain any required amount of draft correctly, a draft template, kept with other tools and templates, will be found convenient and useful, saving much time when changing from one ratio of draft or bevel to another. It is made as follows:

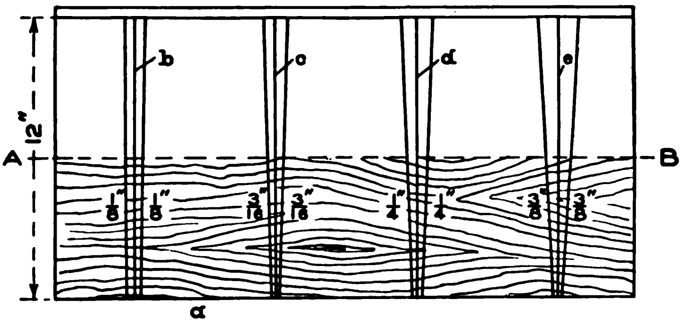


Fig. 135.

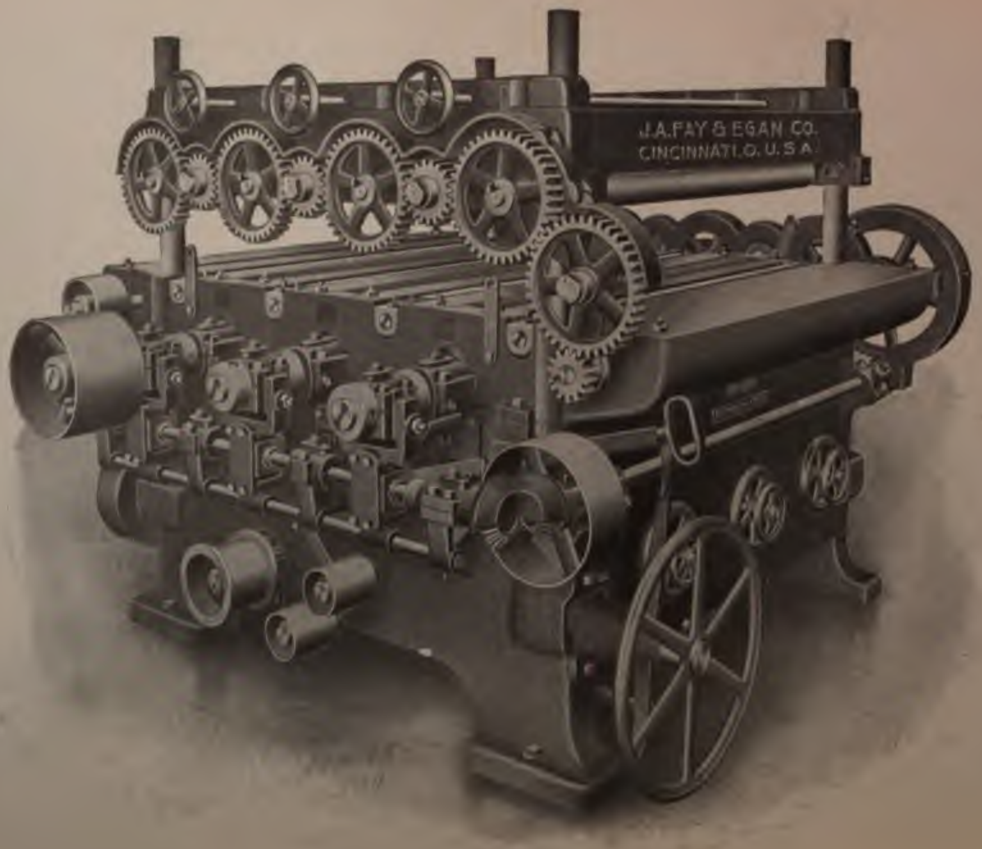
Take any straight-grained board 14 inches to 16 inches long and 12¼ inches wide, as shown in Fig. 135. Having jointed the edge *a* perfectly straight, draw the line *b* perpendicular to the edge and 12 inches long, using a square and a sharp-pointed knife (not a scratch-awl or a lead pencil). On the edge *a* carefully measure ¼ inch on each side of *b;* and at the upper extremity, with the same care, measure ⅜ inch on each side of *b;* connect the last two points thus found with the first two on the edge *a*, by a sharp knife line, and the result will be a right and left slanting line, having, with reference to the perpendicular, a slant of ⅛ inch to a foot. These lines should each be marked "⅛ inch," as shown in the drawing.

Now draw a second perpendicular *c*, at a distance of 1½ inches or 2 inches from the first. On the edge of the board *a*, again carefully mark off ¼ inch on each side; at the other extreme mark off $\frac{7}{16}$ inch on each side of *c*, and again connect the latter points with the former. The result will be a taper of $\frac{3}{16}$ inch to a foot. Again repeat the process, making the taper ¼ inch, and lastly ⅜ inch, to a foot. Mark the pairs of right and left-hand tapers respectively ⅛ inch, $\frac{3}{16}$ inch, ¼ inch, ⅜ inch, as shown. These lines having been obtained permanently, the width of the board may be cut down from 12¼ inches to 6 inches (as shown by the dotted line A B), and the board then shellaced.

To use this template, place the bevel against the edge *a* of the board, and carefully adjust the blade to the ⅛ inch, $\frac{3}{16}$ inch, or other draft, right or left as may be required. It will readily be seen that whatever may be the width of the surface to which the bevel is applied, the taper or draft will be in the exact proportion of the given amount for each 12 inches.

Finish. The term *finish*, in pattern making, refers to the additional amount, after shrinkage and draft, which must be added to the pattern in places where the casting is to be planed, turned, chipped and filed, or "fitted," in the machine shop. The amount that is to be so added is, to a certain extent, though not wholly, independent of the size of the piece. For small articles whose longest dimension does not exceed three or four feet, an addition of ⅛ inch to the surface to be finished is usually sufficient. For larger dimensions it may be necessary to add as much as ¼ inch or ⅜ inch, but very rarely more than this. In making this allowance it is also well to bear in mind the tendency of the casting to warp in cooling. Where the thickness of the metal varies to any great extent, there is a greater liability to warp than if a uniform thickness prevails throughout the whole. Hence, in such cases, a greater allowance must be made for the finishing.

On small pieces and where the moulding is carefully done it may be possible to make as small an allowance as $\frac{1}{16}$ inch, but as a general rule sufficient metal should be put upon the casting to allow



TRIPLE DRUM SANDER.
J. A. Fay and Egan Co.

the cutting tool of the finishing machine to cut well below the surface so that it shall not become dulled by the sand and hard scale on the outside.

A pattern for the plain cast-iron bar illustrated in Fig. 136 will afford a good example of the allowance necessary for finish and for draft. This bar is to be finished all over, the finished sizes being 36 inches long, 1 inch wide, and 1 inch thick.

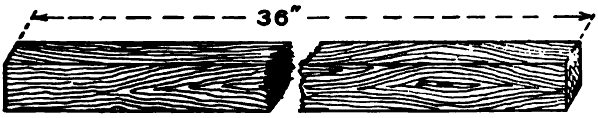


Fig. 136.

A slender bar of this length is liable to warp or bend when cooling in the mould, and for this reason the bar should have an allowance of at least ⅛ inch all over for finish, thus requiring a pattern 36¼ inches long, 1¼ inches wide, and 1¼ inches thick. Moreover, to enable the moulder to remove the pattern from the sand without injury to the mould, we must add on two of the opposite sides a draft of about ¼ inch to the foot, making a cross-section through the pattern of the shape and dimensions as shown in Fig. 137.

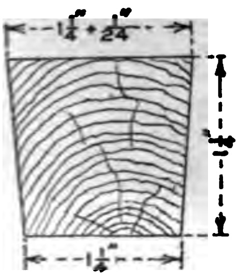


Fig. 137.

When accuracy is required in testing bars 36 inches × 1 inch × 1 inch (which are seldom finished), they are often moulded partly in the cope and partly in the drag, as shown in Fig. 138, the parting being on the line *a b*. In this position the inclination of the sides of the pattern in the mould is so great that no draft is required, the pattern being simply a square bar of wood of dimensions of 36 inches × 1 inch × 1 inch, measured with the shrinkage rule.

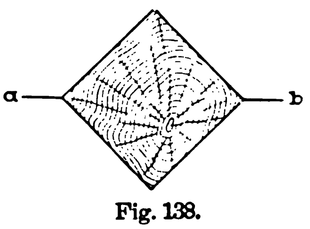
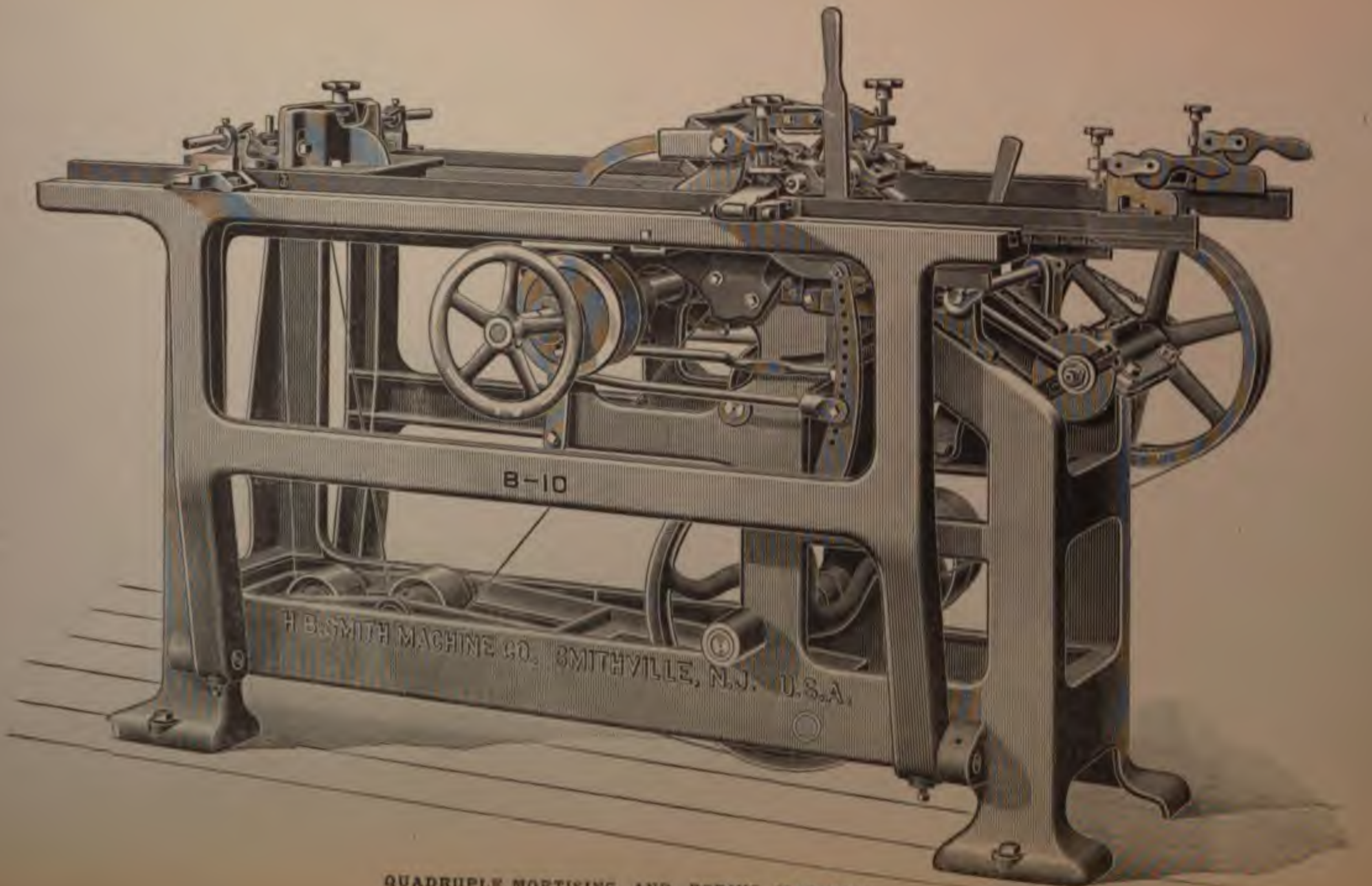


Fig. 138.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QUADRUPLE MORTISING AND BORING MACHINE.
H. B. Smith Machine Co.

PATTERN MAKING.

PART II.

SIMPLE PATTERNS.

The simplest patterns are those which are made in one piece, and which require no coring, although the castings themselves may be hollow.

The first thing which the pattern maker should decide in commencing a pattern, is the way in which it is to be removed from the sand, and where the parting line, if there is one, should be. As an example of a simple pattern of one piece made without a dry-sand core, the stuffing-box gland (shown in Fig. 134, Part I) is a good illustration. It is readily seen that if the pattern of such a gland were to be imbedded in sand, as shown, there is no reason why it could not be lifted out without disturbing any of the surrounding or the internal sand. The drawing represents the pattern with *draft* and *finish* added, the finished gland being shown by the dotted lines.

In every pattern of this kind, forming its own core, it is necessary to allow double draft on the inside, so that the pattern may be rapped and removed without injury to the green-sand core, which at best is not very stable, and which should be used only when the gland or other hollow casting is of such size as to give a large and stable core.

Except in a few special cases, it is much better to put core prints on the ends of the pattern and use a dry-sand core in place of the green-sand core illustrated above, thus avoiding the unnecessary waste of metal added by the double draft on the inside of the casting, and the expense and labor of removing it in the machine shop.

In order to give a better understanding of the methods employed in Pattern Making, the object itself will be illustrated; and when it is to be finished, the finished dimensions only will be given. If the object is not to be finished, the sizes of the completed castings will be shown. These dimensions will, in all cases, be arbitrary, and can be changed at will, if for any reason alteration is necessary. The successive steps in the construction of the pattern are given in detail so that the student may fully understand the principles involved.

The first article for consideration is the *brass bushing* flanged at one end, illustrated in Fig. 139. This bushing is to be finished *all over*, and as the casting is small, $\frac{1}{16}$ inch will be sufficient for outside finish and the same for turning out the inside. On examining it with regard to moulding, we find that if moulded on end with the flange up and on the parting line of the flask it can be readily removed from the mould.

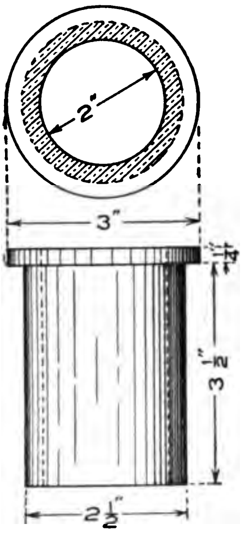


Fig. 139.

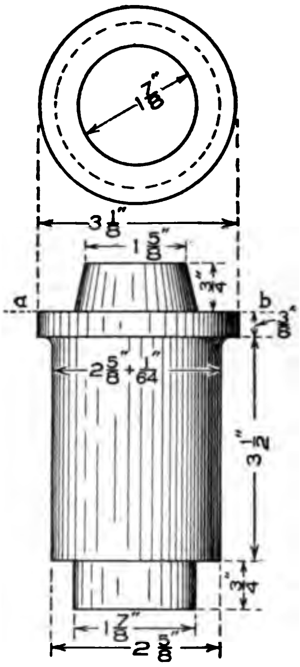


Fig. 140.

The draft in this case should be $\frac{1}{8}$ inch in 12 inches or a little less; and each core print, because the pattern is very short, need not be more than $\frac{3}{4}$ inch long. Having the finished sizes given (Fig. 139), and having decided on the amount of draft and finish, the pattern will be as represented by Fig. 140, and in the case of this simple pattern, as in all others, a full size drawing, or sketch, giving all the dimensions of the pattern, should be made by the pattern maker before beginning work on the pattern. This is good practice, and if carried out many mistakes and much loss of time will be avoided.

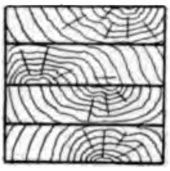


Fig. 141.

The lower core print should have the same proportion of draft as the body of the pattern, but the upper core print is given the excessive draft of $\frac{1}{8}$ inch to its length so that the cope can be easily lifted off and returned again over the tapering end of the dry-sand core without injury to the mould; the parting of drag and cope being on the line *a b*. This pattern may be turned from a solid block of wood, but if durability is desired the block should be glued up from 4 pieces of $\frac{7}{8}$-inch pine, care being taken to reverse the annular rings or yearly growth of the wood, as shown in Fig. 141.

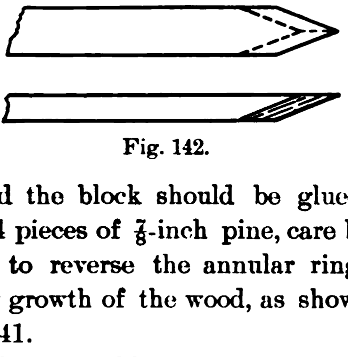


Fig. 142.

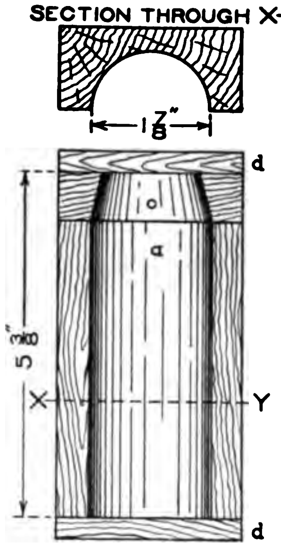


Fig. 143.

Place the block in the lathe and with the gouge turn to a cylindrical form of slightly greater diameter than the largest diameter of the pattern, say $3\frac{3}{16}$ inch. All finishing should be done by the use of scraping tools. For the body of the pattern, a firmer chisel 1 inch wide is a good tool, but the cutting edge must be ground and sharpened slightly rounding, as described for plane irons; otherwise the corners of the tool are liable to catch and form grooves on the surface.

For smoothing and finishing the ends of the pattern and flange, a diamond-pointed scraping tool, Fig. 142, is preferred to all others. The core box for this pattern is shown in Fig. 143, which is representative of the half box used for all symmetrical cores. In this box, two semicircular or half cores are made, which, after being dried, are pasted together, forming the cylindrical core required. For the part *a* of the core box, a block of slightly greater length ($\frac{1}{2}$ inch or 1 inch) is first planed up to the exact size. A center line *b*, Fig. 144, is drawn with the marking gauge parallel to one of the edges, and also extends across each end of the block. From this center line, at a distance of $\frac{15}{16}$ inch on each side, the lines *d* and *e* are also drawn. Then with a second block, or strip of wood placed against the face of the block and flush with the end, the two pieces are clamped together in the bench vise, as shown in Fig. 145. Now with the dividers adjusted to $\frac{15}{16}$ inch, describe on each end of the block the semicircle which will connect the lines *d* and *e* on the ends of the block. This wood may be removed rapidly with a gouge and mallet, smoothed with a round plane of proper size and curve, and finished by sand paper rolled on a cylindrical block having a diameter $\frac{3}{16}$ inch less than the width of the required box.

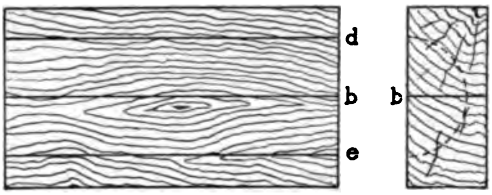


Fig. 144.

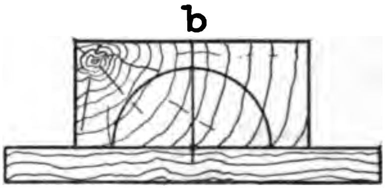


Fig. 145.

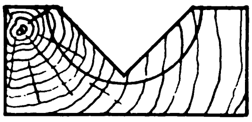


Fig. 146.

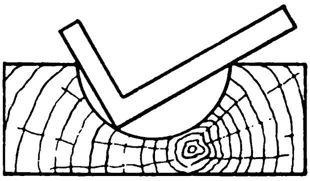


Fig. 146*a*.

Another method frequently used for small boxes, is to work out the center of the curve with a rabbet plane, forming a right-angled opening, as shown in Fig. 146, the remaining wood being removed with the round plane and finished with the cylinder and sand paper as before.

As the work progresses, the accuracy of the curve is tested by means of a try square, or other 90° angle, as shown in Fig. 146a.

The tapered end of the box *c* (Fig. 143) is turned from a block of wood, screwed to the face plate of the lathe as shown in Fig. 147. After the hole is turned to the required depth, $\frac{3}{4}$ inch, and to the required size, $1\frac{7}{8}$ inches on the outside, and $1\frac{5}{8}$ inches at the bottom, it is removed from the face plate and the piece *c* is cut out, as shown by the dotted lines in Fig. 147. This piece *c* is glued and nailed to the end of *a*. The two ends of the box are now given a slight draft. ($\frac{1}{4}$ inch in 12 inches) to allow the half core to leave the box easily. The end strips *d* and *d* (Fig. 143) are then nailed on and the box is complete.

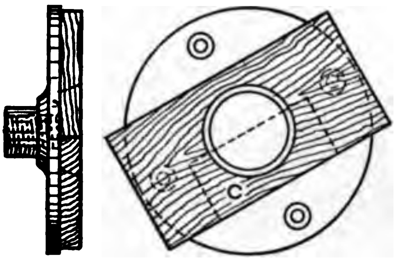


Fig. 147.

FINISHING PATTERNS.

Having completed the pattern and its core box, the surface of the wood must be covered with some material which will render it hard, smooth, and impervious to the moisture in the sand, and at the same time make it easier to be withdrawn from the mould. Pure grain-alcohol shellac-varnish is the best for this purpose. All cheap substitutes, such as wood-alcohol shellac, or copal varnishes should be avoided. They become flaky and scale off, and do not stand the exposure and moisture. Pattern makers generally make their own shellac varnish, buying only the best quality of shellac gum, and using 95 per cent proof alcohol. The proportions are three pounds of gum to one gallon of alcohol. The gum is put in a wide-mouthed bottle, or earthen jar, and the alcohol poured over it, and if well stirred three or four times during the day will (if the alcohol is of the best,) give a smooth, clear, orange-colored varnish ready for use.

A good grade of "white grain-alcohol shellac" may be made from bleached gum, or can be bought from the dealers, but it dries more slowly and does not produce so hard a surface as the orange shellac.

As the alcohol in shellac-varnish evaporates very rapidly, the brush should be kept in a vessel which is closed and air tight. A short bottle having a mouth wide enough to admit the brush is best for this purpose. A one-inch, flat, double-thickness, fitch-hair brush is good for general work. Do not use a cork, but turn a wooden cap for the bottle, such as is shown in Fig. 148. The shoulder at *a* may be $\frac{3}{16}$ inch to $\frac{1}{4}$ inch long, but must be at least $\frac{1}{4}$ inch less in diameter than the inside of the mouth of the bottle. Otherwise the shellac will cement it to the glass so that it cannot be removed. Its only object is to keep the cap nearly central on the bottle. The handle of the brush must be tightly fitted into a hole through the center of the cap and fastened with a screw or brad; allowing the brush to reach within one-half inch of the bottom of the bottle. Keep the bottle one-third to one-half full of shellac and use the brush with the cap on the handle. The shellac will make a tight joint between the bottle and the cap, and if the proper amount of shellac is kept in the bottle, the brush will always remain soft.

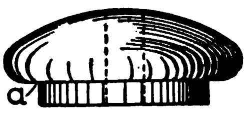


Fig. 148.

For small patterns, such as the bushing described, the small quantity of shellac needed can be used directly from the bottle. For large work however, an earthern-ware cup or mug should be used, but the shellac left over should always be returned to the vessel in which it is kept.

Shellac varnish should never be kept in a metallic can or cup, as the oxidation of the metal will discolor the varnish.

Having given a perfectly smooth surface to the pattern and core box by the use of very fine sand-paper, (No. 0) apply the first coat of shellac. This first coat will raise the grain and roughen the surface of the wood, which, after the shellac is perfectly dry, must be sand-papered a second time until smooth. Now apply a second coat. Should there still be roughness, a second sand-papering will be necessary. At least three coats of shellac should be used. If there is much end wood exposed on any of the surfaces of the pattern, a fourth coat may be necessary on these parts.

As regards the color in which patterns are finished there are different rules in different shops. The general rule, however, is to leave all patterns for brass or bronze, in the natural color of the wood, and shellac the core prints red. If the pattern is intended for moulding cast iron, the body of the pattern is made black and the core prints red. The parts of the core box in which the core is to be formed are also colored red and the outside of the core box black. The black color is produced by mixing lamp black with the shellac varnish, and the red color by mixing vermillion (Chinese is the best) with the shellac. The vermillion is heavy and will settle, hence it must be stirred or well shaken before using. The best method is to first use two coats of the natural colored shellac (orange or white) on all surfaces of the pattern, core prints and core box, then apply the black or red for the last coat only.

As the pattern already described is for a brass bushing, the body should be left the natural color of the pine, and the core prints on the pattern and the inside of the core box colored red.

The outside of the core box may be left the natural color or made black, as preferred. The outside of the core box, having no part in the formation of the core, is not necessarily so well and smoothly finished as the inside.

All nail holes or any defects in the wood should be filled with beeswax applied with the warm blade of a knife, or narrow chisel, warmed by holding in hot water. The beeswax should always be used after the first coat of shellac has been applied, as it will then hold better. The sand-papering of the pattern, after the first coat. will smooth the wax and bring it even with the surface of the wood. The time required for a coat of shellac to dry is from eight to twelve hours, depending upon how heavily it may have been applied, even though to the touch the surface may seem dry in one or two hours.

If a hard, *durable* surface is required on the pattern, twelve, or better, twenty-four hours must be given between each coat. The roughness will then sand-paper off as a dry powder without gumming the sand-paper, and leave a hard, smooth surface for the succeeding coat of shellac.

The second casting to which attention is called, is the ***brass bearing*** represented in Fig. 149, which is to be finished all over. On examining the drawing, first with regard to removing the pattern from the sand, we find that it must be moulded on its side, and that the moulder may not lose time in cutting away the sand (see Figs. 113 and 114, Part I) the pattern must be *parted*, or made in two halves.

For finish on this small pattern $\frac{1}{16}$ inch will be sufficient, and draft will be required only on the ends of the pattern, and on the ends of the core prints, which in this case, should be not less than 1 inch long. This is necessary, because the core-print moulds must sustain the weight of the dry-sand core.

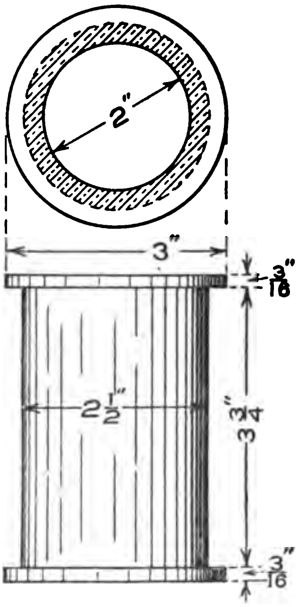


Fig. 149.

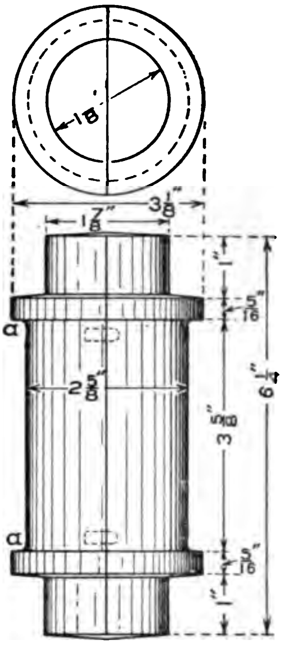


Fig. 150.

The pattern for this casting is represented by Fig. 150, in which it is seen that, unlike Fig. 140, the body and core prints are perfectly straight, a slight draft $\frac{3}{16}$ inch to 12 inches being given to the ends of the pattern and to the ends of the core prints only. A slight curve of $\frac{1}{16}$ inch radius should also be made at the intersection of the body of the pattern, and the inside of the flange at *a*, *a*.

The wood in being prepared for this pattern should be cut $2\frac{1}{2}$ inches longer than the finished pattern. The dimensions of the two halves would each be 1¾ × 3⅜ × 8¾ inches. Having fitted the two insides accurately together and dressed one edge of each straight and at right angles to its face side, with the marking gauge, draw a center line on each, not only on the face but also across each of the two ends, Fig. 151. Across the center of each piece draw, with a sharp-pointed knife and try square, a second line at right angles to the first and at equal distances from each end of the block. With dividers adjusted to 1⅞ inches, place one leg at the intersection of the two lines, and on the gauge line mark two dots, each 1⅞ inches from the center line. These dots are the centers for the dowels which are to connect the two halves of the pattern after it is finished. Bore the holes in each piece ½ inch deep with a $\frac{5}{16}$ inch auger bit, and cut the dowel pins only ¾ inch long, gluing them into the holes of one piece and giving a projection of ¼ inch to fit in the holes of the second half of the pattern. Although the dowels are glued into the first half they must fit easily, but not loosely, in the second, and should be rounded on the ends or made cone shaped, as in Fig. 152.

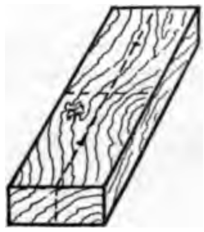


Fig. 151.

Having fitted and prepared the two blocks with their dowel pins, carefully glue them together using only a narrow strip of glue ½ inch wide on each end of the block and clamping the two together with a hand screw on each end. When the pressure of the hand screw is applied, the glue will spread inward to ¾ inch or 1 inch. Great care must be taken not to use too great a quantity of glue, or it will spread in far enough to bind the two halves of the pattern together so that they cannot be separated when turned and finished. The blocks should remain in the hand screws, after

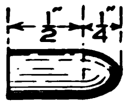


Fig. 152.

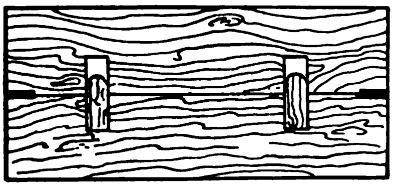


Fig. 153.

being glued, from four to six hours, depending on the temperature of the room in which the gluing is done. Our pattern block is now ready for the lathe and will be as represented in Fig. 153, which is a longitudinal section through the dowel pins.

When centering for the lathe centers, great care must be taken to mark the centers exactly at the intersection of the center-gauge lines on the ends of the blocks and the glued joint of the two pieces. The hard glue will force the lathe center to one side of the connecting joint unless a center dot or hole is first made with an awl in the exact position required. As in the case of the pattern in Fig. 140, the block is roughly turned to dimensions, all of which are a little larger than the finished pattern, by using the ordinary turners' gouges, but the final turning and finishing to exact sizes must in all cases be made with scraping tools, as described for the pattern of the *brass bushing*.

When marking off the pattern on the rounded cylinder in the lathe, care must be taken to locate the pattern in the exact center of the block, so that the dowel pins may be equally distant from each end and from the center of the pattern. Fig. 154 shows the pattern as ready to be taken from the lathe. The core print ends should be cut down to ¾ inch at each end, and finally cut off with a saw, and the ends finished with file and sand paper after removing from the lathe, when, as will be seen, the glued end having been cut off, the two halves of the pattern will separate clean and free from glue, and the dowel pins will always bring them into accurate alignment when used by the moulder in the foundry. Before removing the turned pattern from the lathe, it should be smoothed and finished with sand paper, but care must be taken not to allow the sand paper to come in contact with the sharp corners and angles of the pattern, or they will be rounded off and the work ruined. For pine, only the finest paper, No. ½ and No. 0 should be used on lathe work, and the paper must not be held in one position on the revolving work but must be kept moving laterally, that is, from side to side, to avoid cutting depressions in the surface.

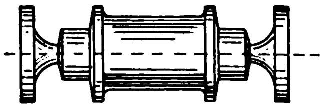


Fig. 154.

When the scraping tools are kept sharp so that they will cut freely and without pressure, a light touch of sand paper only will be required.

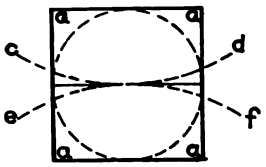


Fig. 155.

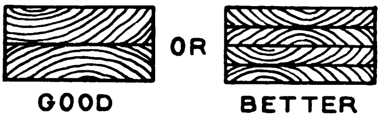


Fig. 156.

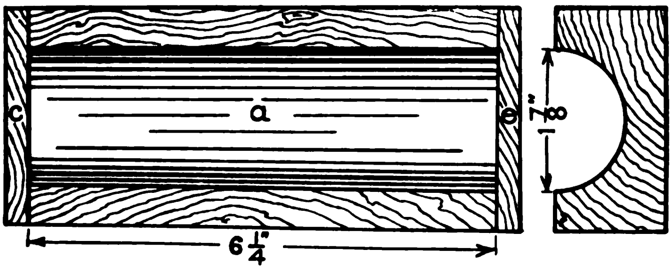


Fig. 157.

In the construction of this pattern, it may be made of two blocks of 1¾-inch stock as described; but the tendency of the two halves will be to become rounding on the parting line as shown by the dotted lines *c d* and *e f*, Fig. 155. This is caused by the removal of considerable wood in the process of turning, at the angles *a a a a* thus exposing fresh surfaces which are farther removed from the original surfaces of the plank, than the surfaces on the line of parting. The exposure of these deep, inside fibers of the wood will cause a shrinkage of the pores and draw the pattern more or less, according to the position of the annular growths, and also to the more or less thorough seasoning of the wood, in the direction indicated. If the pattern is intended for temporary use only, it may be constructed as above, but if durability and permanence of shape are required, the two blocks should each be glued up out of thinner stock with the annular growths carefully reversed, as shown in Fig. 156. This is done not only because thin plank is more evenly and better seasoned, but because in gluing, the tendency of the pieces to warp or spring is counteracted each by the other, and in addition the gluing of several thin pieces together stiffens and makes the resulting piece much firmer and stronger than a large block or piece of the same size obtained without gluing.

The core for this pattern, being straight from end to end, and cylindrical, only a half core box is required, as shown in Fig. 157. After being laid off and worked out in the same manner as described for the core box, Figs. 143 and 144, cut the ends of *a* with draft of ¼ inch in 12 inches, and glue and nail on the ends *c* and *e*, which may be ⅜ inch to ½ inch in thickness.

Shellac and finish as described for pattern, Fig. 140, giving first two coats of orange or white shellac, and for the last coat on core prints of the pattern and the inside of the core box *a* use the red, the body of the pattern being left natural color (with three coats) and the outside of the core box either natural or black.

GLUING.

As the use of glue enters largely into the construction of all patterns, some instruction as to its selection and the manner of using will be necessary. When building up patterns, the connections should in all cases be made by gluing. Nails should never be used except when they can be so placed as to be entirely removed from all danger of contact with the tools used in turning and shaping the pattern, and when so employed should be used in conjunction with glue. The only advantage in their use is the hastening of the work, because they take the place of hand screws or clamps while the glue is drying.

The use of nails, however, is always unsatisfactory, for when the point is passing through the upper piece, small thin slivers are broken from the under surface, which have a tendency to separate the two surfaces instead of exerting the required pressure as when hand screws are used.

For pattern work select only the very best quality of cabinetmakers' glue, or better still, the best quality of white glue. This white glue can always be had in two forms, first, white glue, *clear*, and second, white glue *opaque*. The first is the glue without the addition of any foreign substance. The second looks much whiter than the first, because of the addition of whiting, or other mineral, to the glue. This addition does not in any way lessen the adhesive qualities of the glue; on the other hand, it sets more readily and dries more quickly, but for this very reason, it is harder to use on large surfaces, as the first brushing on one part of the work will begin to set before the entire surface can be covered. For all small or moderate-sized work, however, the opaque, white glue is to be preferred.

Good glue will keep in a dry room of any temperature for an indefinite length of time, but when cooked in the glue-pot it deteriorates very rapidly. Each successive reheating and boiling lessens its adhesive qualities, hence it should always be used *fresh* or nearly so. A greater quantity of glue than is likely to be used in two or three days should not be cooked at one time.

The cooking and preparing must be done in the regular glue-pot, made for the purpose, and sold in all hardware stores. No rule can be given for the relative quantities of glue and water to be used. Some glues, especially the cheaper grades, require much less water than the better and finer qualities. As a general rule however, pack the glue firmly in the pot and add sufficient cold water to cover it. Fill the outside kettle with cold water and boil until thoroughly cooked, so that it will run smooth and clear from the brush or paddle. It should run freely without returning and gathering in bunches or clots at the end of the paddle, but must not be so thin as to be weak and watery.

If the glue is too thick, no amount of pressure will bring the two glued surfaces in close contact, and if too thin there is danger that the joint will not hold. Always use cold water for cooking and dissolving fresh glue. Hot or boiling water will make the glue *stringy* and will require a much longer time to cook to an even and smooth consistency. Great care should also be taken to keep the outside kettle, which surrounds the glue-pot proper, full of water. If allowed to *boil dry* the glue in the inner pot will be scorched, or burned, and will then be entirely useless. It must then be thrown out, the pot washed or boiled out clean, and fresh glue again cooked. The hot water in the outside kettle should in all cases be used for thinning the glue to the required consistency. Cold water chills the glue and necessitates reheating. In cold weather the precaution must be taken, unless the room is warm and entirely free from drafts, to heat the pieces of wood before applying the glue, else the latter may be chilled and fail to set. The time required for well-made joints to dry so that the hand-screws can be removed is from four to six hours.

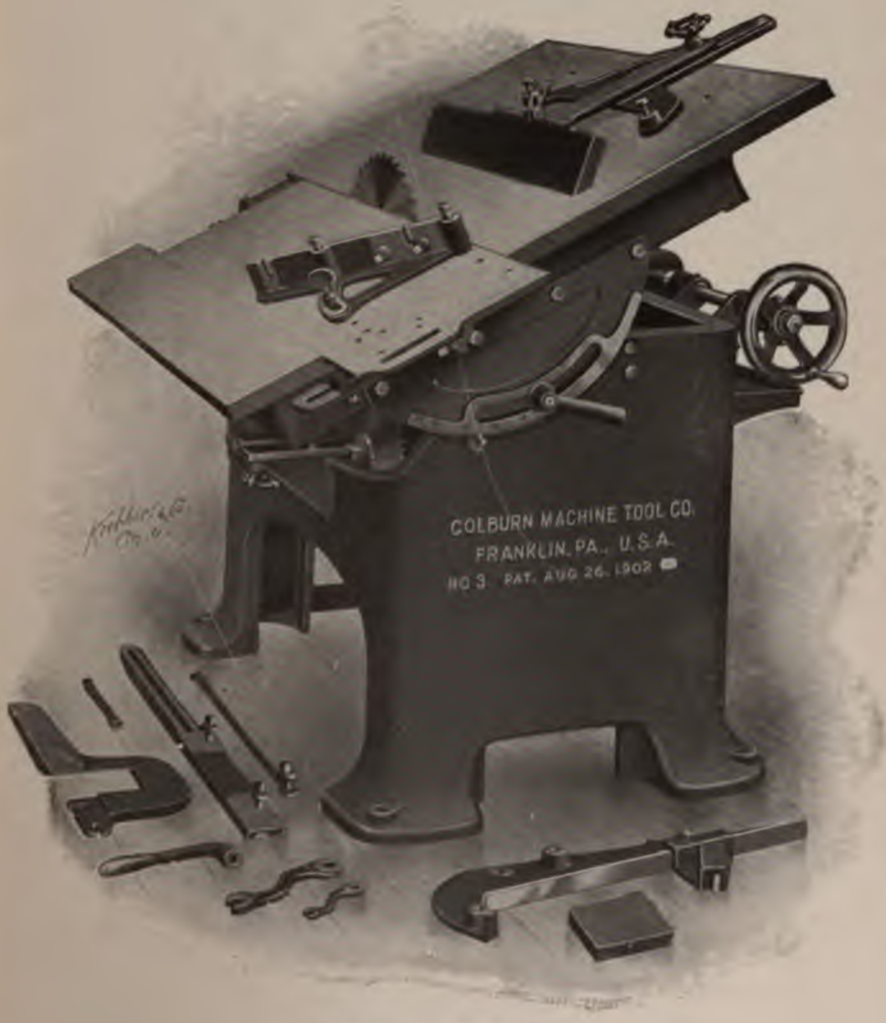
Sometimes a difficulty will arise in the case of large surfaces on thin material. When the glue is applied it moistens and expands the surface upon which it is placed, causing the edges to curl up and pull away from the adjoining piece which has a tendency to move in the opposite direction. In such cases *never* moisten the back of the thin pieces with water from the outside kettle, as is sometimes directed, but work quickly, spreading the glue rapidly and then place between two thick, stiff pieces of board, previously dressed true, prepared and heated for the purpose. Use as many hand-screws as can be conveniently placed on the work, and allow it to remain in these clamps until all moisture from the glue is absorbed by the two outside, heated boards. Twenty-four, or better forty-eight, hours should be given to this process if possible.

All such gluing of thin pieces should in every case be done first and allowed to dry while the other parts of the pattern are being constructed. Under no circumstances use water on any surface of seasoned wood. The reseasoning or drying out of such water will invariably distort, curl, and warp the pieces so treated after being glued together. Even the water contained in the glue is objectionable, while unavoidable, and can be most satisfactorily removed only as directed above.

In all cases where end wood is to be glued, or where the grain of the wood runs diagonally to the plane of the joint so as to present the open end wood pores for the glue, this end wood, or partially end wood joints, should be first "*sized*" with thin glue, (glue about half the thickness of that used for gluing,) and allowed to dry. This will raise the grain and roughen the surface of the joint, which, when dry, must be lightly and carefully scraped off with a sharp chisel, when it will be found that the open pores of the wood are filled with dried glue. The joint may now be glued, and the glue will hold as in ordinary jointing.

HAND SCREWS.

The hand screws, illustrated in Fig. 81, enter so largely into all gluing for pattern work, that some description of their con-



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Coburn Machine Tool Co.

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struction and the manner of using is necessary here. The four parts of each hand screw consist of two *jaws* and two *spindles*. When using, the *jaws* must in every case be kept parallel. This is done by the adjustment of the middle or central spindle. The clamping is in all cases done by the outside or end spindle, the middle or adjusting spindle serving as a fulcrum for the jaws; the leverage and pressure being obtained by the end spindle. When clamping broad surfaces, care must be taken to see that the pressure of the jaws on the work being glued is the same at the points and at the back part of the applied portion of the jaws.

This can be easily changed at will, by slightly loosening or tightening the middle spindle, which, as before stated, is the adjusting spindle and fulcrum, and not used for clamping. After adjusting the jaws parallel and to even pressure on all their length as applied to the work, screw up and tighten the end spindle to the utmost pressure which the jaws will bear, and again examine the clamp and the work to see if the jaws are parallel and the pressure even.

If not, loosen the end spindle and readjust the middle spindle by opening or closing as the case may require. To open and close the hand-screws for larger or smaller work, *do not* screw or unscrew *one* spindle at a time. Instead, grip the handle of the *middle* spindle in the left hand, and the handle of the end spindle in the right hand. Hold the hand screw at arms length and whirl it from or toward you as may be needed for closing or opening the jaws In this way the spindles will each be kept in its proper relative position, and the jaws will, at all distances, remain parallel.

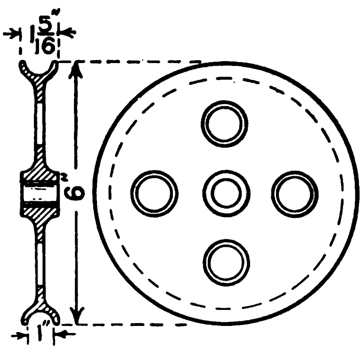


Fig. 158.

BUILT UP PATTERNS.

A good example of the manner in which patterns are built and glued up is shown in the construction of the pattern for the 6 inch sheave pulley shown in Fig. 158.

The groove is a semicircle 1 inch wide, and the rim containing the groove is connected with the hub by a solid web ¼ inch in thickness, and having four or six holes, each 1 inch in diameter, this web taking the place of arms. If there is to be no *finish* on the sheave, as is usual, the only allowance to be made on the pattern, *which must be parted*, will be for shrinkage and for draft.

A cross-section through the finished pattern for this casting is shown in Fig. 159.

In all large patterns of this kind, the web is first glued up in sectors, six, eight or more in number, according to the size of the sheave (see Fig. 160). The sectors are fitted by hand or on the trimmer, the ends are glue-sized, and when the sizing is dry the joints are carefully scraped smooth, and the whole glued together. After drying for four or five hours, it is sawed to a circle of ⅛-inch greater diameter than the finished pattern, and the block for the hub is glued over the center. Six segments to form the outer rim are glued around on the outer edge, care being taken to *break joints* as shown in Fig. 161. If the groove is to be large, the six segments should be of half the thickness only, and a second set of segments of like thickness glued over the first, *breaking joints* not only with the first set, but also with sectors of the web.

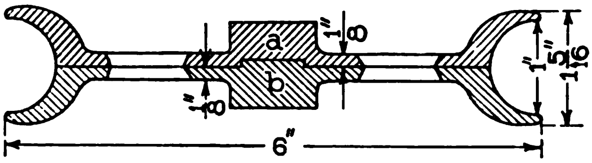


Fig. 159.

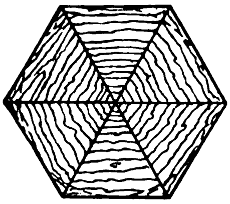


Fig. 160.

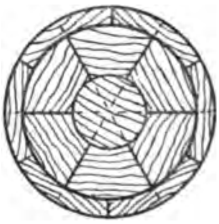


Fig. 161.

In other words, in all glued-up rims, no two joints should be directly over each other. All joints must be so *broken* and so distributed as to give the greatest possible strength to the rim. In the present case, our pattern is so small that it is only necessary to use a thin board, ¼ inch in thickness for each half of the web. After sawing to 6½ inches in diameter, ½ inch for turning, a block ½ inch in thickness is glued on the center of each to form the hub; and six segments 1¼ inches wide and ½ inch in thickness, are glued around on the outer surface of each to form the rim and groove, as shown in Fig. 162.

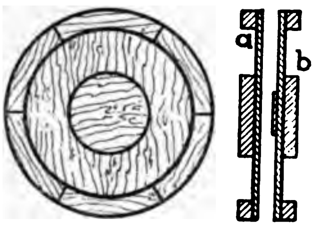


Fig. 162.

Care must be taken to place the segments so that the grain of the web will be crossed by two of the segments as shown in the drawings.

On the second half *b* of the pattern, a thin circular block ¼ inch in thickness is glued on the inside opposite to the hub block, to form the projection (⅛ inch) which will keep the two halves of the pattern in alignment, as shown in the cross-sectional drawing in Fig. 159. Having glued up the stock as described, and as shown in Fig. 162, the outside must be planed to a level surface, or so that the six segments forming the rim and the center hub block will be in the same plane.

The half pattern is now screwed on the screw chuck of the lathe as illustrated in Fig. 163, and the inside, or the parting face *c*, is turned perfectly straight and true. The edge is turned down to 6 inches in diameter, and the quartered circle shown by the dotted lines is carefully shaped. A template, made as shown at *d*, will assist greatly at this stage of the work. A recess is turned at the center, and in the face of *a*, Fig. 159, 1½ inches in diameter and ⅛ inch deep, to receive the corresponding projection on the half pattern *b* which is to keep the two halves in alignment.

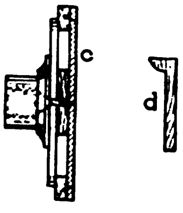


Fig. 163.

The half pattern *a*, is now removed from the screw chuck, and the second half *b* is screwed on and turned in the same manner except that the central projection is carefully turned to fit in the recess in *a*.

Before removing *b* from the chuck, test by trying the second half *a*, and change *b* until a perfect fit is obtained between the two halves, not only in the central recess and projection, but also in the two curves which form the semicircular groove of the rim. A cross-section of the pattern at this stage of construction is shown in Fig. 164.

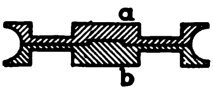


Fig. 164.

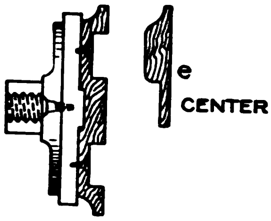


Fig. 165.

A disc or chuck of wood 5½ inches in diameter is now screwed to the iron face-plate, or the screw chuck, and turned off true on the face with a projection ⅛ inch high which will fit into the recess in the middle of the parting face of *a*. This projection will center the half pattern *a* on the face plate, and it can be held in position by two or four short wood screws driven through the web into the wooden chuck as shown in Fig. 165.

Care must be taken to place the screws in such a position that the screw holes will be cut or bored out when making the four or six openings 1 inch in diameter in the finished web of the pulley.

The screws must be small and slender and the heads well countersunk out of reach of the turning tools. The face of the half pattern is now turned to the required shape, the template shown at *e* in Fig. 165, being used for the purpose. Having finished with fine sandpaper, remove the half pattern, and turn off the projection on the center of the wooden chuck; turn a recess instead to receive the projection on *b*, and proceed with this second half as with the first. If the wood has been well seasoned, and the work carefully done a perfect 6-inch sheave pulley pattern will be obtained. such as is shown in Fig. 159.

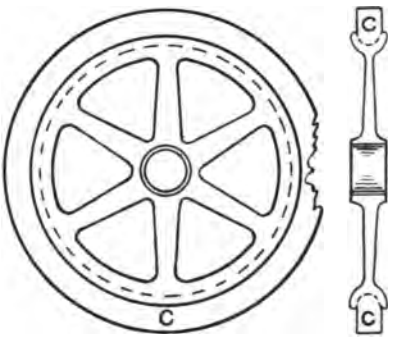


Fig. 166*a*.

The pattern for a sheave pulley has been explained because it embraces so many profitable points and conditions, not only in gluing and building up, but especially in chucking and turning, all of which must be done with great care and accuracy.

The 1-inch holes in the web are bored out with a 1-inch *center bit*, which, when well sharpened, will not split or splinter the thin webs of the two halves of the pattern, if care is taken to reverse the bore from the opposite side when the point of the center bit comes through. The holes should be given a slight draft as shown in Fig. 159, with a small half-round cabinet file. When very large sheave pulleys, having arms, are to be made, such as are common for power transmission by rope or cable, the patterns are not halved but are made in one piece and the groove is *cored* around the rim. Such a pattern is illustrated in Fig. 166*a*, with a wide core print *c c* extending entirely around the periphery of the pattern.

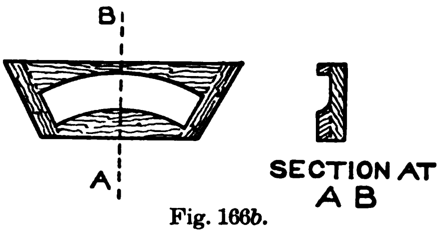


Fig. 166*b*.

A segmental core box is made for one sixth or one eighth the circumference of the wheel, as shown in Fig. 166 *b*, and here again only half of the core box for a full core is needed. When coring the rim as above, the core print must be made wide, at least two to three times the depth of the groove, so that the core may rest firmly and remain in position without tilting while the metal is being poured into the mould.

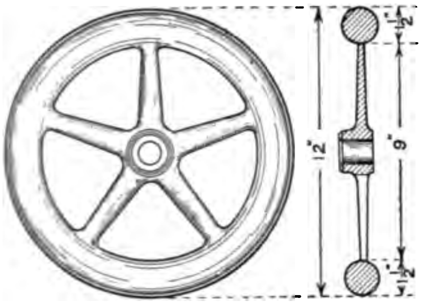


Fig. 167.

The 12-inch hand wheel, Fig. 167, with five arms and a round rim finished to 1½ inches in diameter, will also serve as a good illustration of pattern construction. On the rim of the pattern, $\frac{1}{16}$ inch over all its surface must be allowed for *finish*, making the diameter of the rim of the pattern 1⅝ inches, and the outside diameter of the pattern 12⅛ inches, while the inside diameter of the rim will be 8⅞ inches.

The rims of such patterns are usually turned in two halves. A wooden chuck, in this case a plain board 12¾ inches in diameter, and ⅞ inch to 1⅛ inches in thickness, is screwed to the iron face-plate of the lathe, and turned true on the face and on the edge to 12½ inches in diameter. Ten blocks 2½ inches long, 2 inches wide, and ¾ inch in thickness are glued radially at equal distances around the face of the chuck as in Fig. 168. These blocks are turned even with the edge of the chuck, and the faces are also turned off true and straight so as to form a joint with the first row of rim segments.

The segments, ten in number, five for each layer, are sawed from a ½-inch board, and should be 2 inches wide.

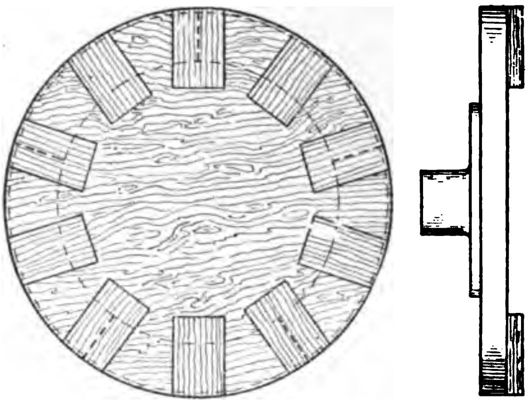
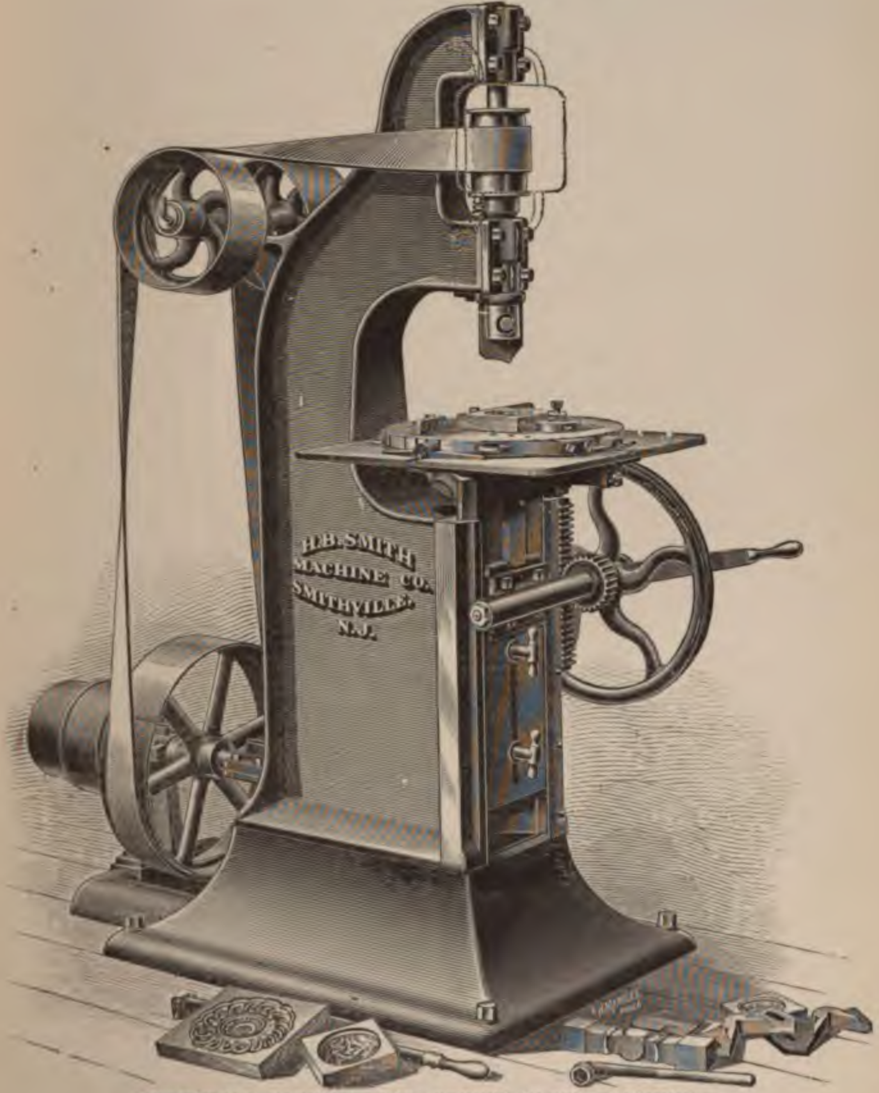


Fig. 168.

Five of these are carefully fitted and glued to the face of the blocks, as shown by the dotted lines in the drawing; and when the glue is dry the chuck is returned to the lathe, and the face of the segments turned flat and true to receive the second row, which is fitted and glued to the first.

Small hand screws must be used, three on each segment, to press the first layer to the blocks, and again to press the second layer to the first. The joints of the second layer must be over the middle of the alternate blocks from the joints of the first, so as to break joints with the first. When the glue is dry, place the chuck in the lathe, and turn the half rim thus constructed to a true semicircle with an outside diameter of 12⅛ inches and an inside diameter of 8⅞ inches, using a semicircular template of sheet zinc or copper to test by while turning.



GEOMETRIC CARVING AND CORNER-BLOCK MACHINE.

H. B. Smith Machine Co.

When turned and sand-papered, cut from the block of the chuck by using a ⅛-inch parting or cutting-off tool, care being taken to cut close to the segments forming the half rim. Turn off the face of the blocks on the chuck true and straight a second time, and construct and turn the second half of the rim in the same way as described for the first; but great care must be taken to make the two diameters, outside and inside, of each half exactly alike, otherwise the work on one half will be lost. As it is difficult to hold these two half rims for planing and fitting together, a concave and semicircular groove turned in the face of a second board, or chuck, in which they can be laid while being planed or fitted, will be found useful.

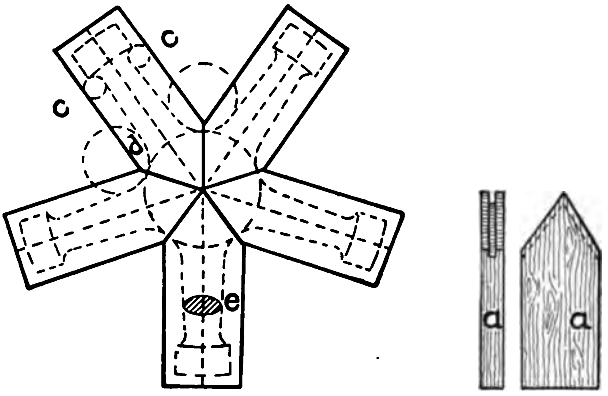


Fig. 169.

In all rim work of this kind the circular segments should be cut lengthwise with the grain of the wood, the object being in this construction, to do away, as much as possible, with all end wood.

While waiting for the separate layers of glued segments to dry, the arms should be made so as to be ready for the two half rims when completed.

The arms in this case should be made ⅝ inch in thickness at the hub and ½ inch in thickness where they enter the rim of the wheel. The construction is as shown in Fig. 169.

Five pieces, each 5¾ inches long, 2⅛ inches wide, and ⅝ inch in thickness are necessary. After being carefully fitted on the trimmer, a saw kerf $\frac{5}{16}$ inch deep is cut in each joint (*a*, Fig. 169), into which a thin tongue of wood is inserted and glued, the tongues serving as tenons to hold the arms together. After fitting, and before grooving with saw kerf, the joints must be glue-sized and, when dry, carefully scraped smooth with a sharp chisel.

The grain of the wood in the tongues must run at right angles to or crosswise of the joint to insure the greatest strength.

When glued together and dry, from the center or intersection of the five pieces, mark with dividers set to a radius of 5¼ inches, and cut off the ends of the arms so that they will project each halfway into the rim.

From the same center describe a circle 3½ inches in diameter, forming the web of the arms; and from this 3½-inch circle, taper the arms to ½ inch in thickness at the ends, care being taken to plane the same amount from each side, and to dress the arms evenly so that they will revolve in the same plane. This being done, from the center describe arcs on the outer ends of the arms, with a radius of 4⅜ inches (8¾ inches diameter, which is ⅛ inch less than the inside diameter of the rim), and divide the imaginary circle thus formed into five equal parts with the dividers. Draw radii from the points thus obtained, to the center. These radii will be the central lines of the arms, as shown by the dotted lines in Fig. 169.

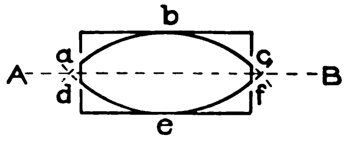


Fig. 170.

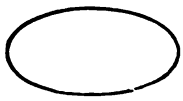


Fig. 171.

On each side of the intersection of the radii and outer circle, measure ½ inch to the right and left, and on the circle denoting the circumference of the web, mark 11/16 on each side of the radii; connect the points thus obtained, and the result will be five arms 1⅜ inches wide at the web and 1 inch wide at the rim, as shown in the drawing. The ends of the arms which enter the rim should be, in this case, 1¾ inches wide, and the sides are drawn parallel to the radius which marks the center of each arm. The curves which connect the arms at the hub must be drawn of such radius as to make the curve tangent to the circle forming the extremity of the web, and also tangent to the sides of the two connected arms as shown at *d*. The small circles at the intersections of the arms with the rim, must be tangent to the edge of the arm and to the circle (8¾ inches diameter) which marks $\frac{1}{16}$ inch less than the inside diameter of the rim as shown at *c c*.

Having laid out the arms as above, and as shown in the drawing by the dotted lines, saw them to shape and round them up to an elliptical form as shown in the cross-section at *e*, Fig. 169. The finished shape of the arm at any point in its length, is found by drawing a cross-section of the arm at that point, as in Fig. 170.

Divide the cross-section equally by the line A B; measure $\frac{1}{16}$ inch; as at *a c d f*; and with dividers adjusted so as to be tangent to the sides of the cross-section of the arm, and to pass through *a c* and *d f*, draw the curves *a b c* and *d e f*.

After filing and working off the sides of the arms to these curves, the angles at *a c d* and *f* are carefully rounded with sand paper, care being taken not to lessen the width of the arm at any point. The result will be as shown in Fig. 171, which gives a strong, firm edge to the arm, and one which will not break or splinter off while being rammed up in the sand.

The arms thus shaped and finished are cut or *let* ¼ inch into each half of the rim, and great care must be taken to keep them central with the rim. Before marking the rim for the mortises which will receive the ends of the arms, test their positions with the dividers, spacing from the center of the arms to the outside edge of the rim, and moving the arms until a central position is obtained; after which, with the point of a knife or awl, scribe around the end of each arm, and proceed to cut, with a chisel, the mortises ¼ inch deep into each of the half rims, and so cut and fit that the two pieces of the rim may meet and form a close joint, after which they are glued and clamped together over the arms with hand screws.

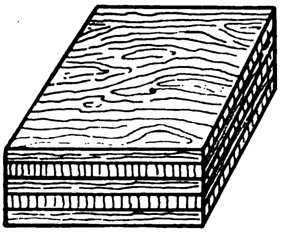


Fig. 172.

The hubs are next turned, each from a solid block, or better from thin pieces ¼ inch to ⅜ inch in thickness, each thin piece being placed crosswise on the other, as shown in Fig. 172. The hubs must be turned with a draft or taper of ⅜ inch to 12 inches, and have a curve of ¼-inch radius at the base where they unite with the arms. After gluing on the hubs, smooth off all connected parts of rim, arms, and hub, and finish with three coats of shellac, sandpapering smooth between each coat, as already described for other patterns.

The making of patterns for special pulleys enters largely into the work of many pattern shops. In these patterns the rims are built up of segments ⅜ inch to ½ inch in thickness.

To illustrate this work fully, let us take up the successive steps in the construction of a countershaft pulley 20 inches in diameter and of 6-inch face, made to fit a shaft 1¾ inches in diameter. The pattern for such a pulley is shown in Fig. 173. The diameter of the web of the arms is 5 inches, and the diameter of the hub 3½ inches at each end and tapering to 3¾ inches in diameter at the arms.

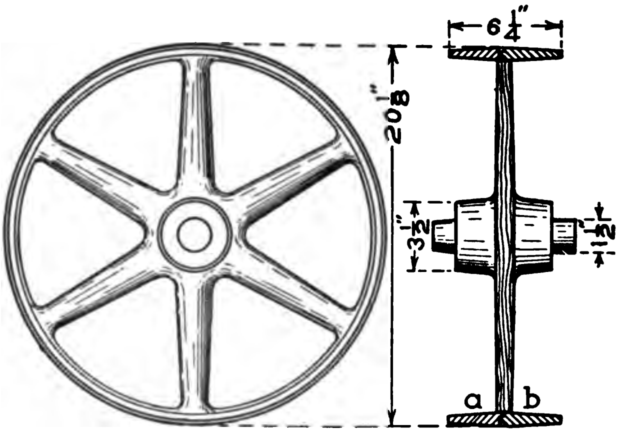


Fig. 173.

If the rim is to be finished on the face and edges only, $\frac{1}{16}$ inch must be allowed for turning, making the outside diameter of the pattern 20⅛ inches, and the width of the face should be 6¼ inches.

In addition to $\frac{1}{16}$ inch for finish, the draft on the outside of the rim, from each edge to the center, should be in the ratio of ⅛ inch to 12 inches, and on the inside of the rim the draft must be ⅜ inch to 12 inches.

The thickness of the rim at its edges will be $\frac{5}{16}$ inch, and with outside and inside draft added, its thickness at the arms will be about $\frac{7}{16}$ inch. The inside diameter of the rim at the arms will be nearly $19\frac{3}{32}$ inches. This pulley should have six straight arms

¾ inch in thickness at the hub and ⅝ inch in thickness at the rim. The width of the arms at the web should be 1¾ inches and at the rim 1½ inches exclusive of the connecting curves at web and rim. Six pieces 10½ inches long, 2¾ inches wide, and ¾ inch in thickness, must be carefully fitted as shown in Fig. 174.

After fitting, the connecting joints are glue sized, and when dry carefully scraped smooth with a sharp chisel, and a saw kerf $\frac{5}{16}$ inch deep cut in each. The tongues used for tenons in these kerfs should be a little less than ⅝ inch long, the grain of the wood running always at right angles to the line of the joint to give the greatest strength to the tenons.

The six pieces should be glued in two groups of three pieces each; and when dry, these two groups can easily be refitted, if necessary, and glued.

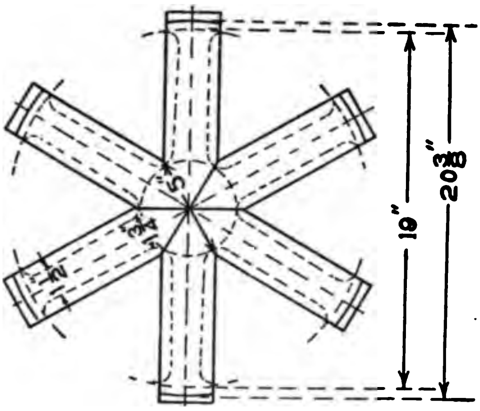


Fig. 174.

The next step is to draw, from the center formed by the intersection of the six pieces, a circle 5 inches in diameter, representing the web of the arms, and, near the extremities of the pieces, the arcs of a circle 20⅜ inches in diameter, representing ¼ inch greater diameter than the outside diameter of the rim. Carefully divide these last arcs into six equal spaces with the dividers, bringing the points thus obtained as nearly to the middle of the six arms as possible; and from the six points thus spaced, draw radial lines connecting them with the center or intersection of the six arms. These radial lines (shown dotted in the drawing) will be the center line of each arm.

Saw off the ends of the arms on the above 20⅜-inch arcs, and from the center again draw on the six arm-pieces a third circle, whose diameter should be at least ⅛ inch less than the inside diameter of the rim, in this case 19 inches. On these arcs measure ¾ inch on each side of the center line, and on the circle representing the web, measure ⅞ inch on each side; connect these points from web to rim, and the arms will be 1¾ inches wide at web, and 1½ inches at the rim.

These lines are shown by the dotted lines in Fig. 174. The width of the ends of the arms passing through the rim should be about 2½ inches, and the sides drawn parallel with the center line of the arm, as shown for hand-wheel arms in Fig. 169. The radius of the circle connecting the sides of the arms and the web, must be such as to be tangent to the edges of the two connected arms, and also tangent to the circle marking the diameter of the web.

The smaller curve connecting the two edges of each arm with the rim must be of such radius as to be tangent to the arm and to the 19-inch arcs which mark the inside of the rim (less ⅛ inch). All these lines are shown dotted in Fig. 174. The arms are now ready for sawing to shape on the band or scroll saw, care being taken to saw just *outside* of the lines so that each arm may retain its full size and width.

After sawing to shape, the edges must be dressed smooth and free from all irregularities of the sawing.

Next, from the web circle, taper the arms to ⅝ inch in thickness at the extreme ends, care being taken to see that the taper of both sides of the arms is uniform from the web circle to the rim.

The shape of the arms should be elliptical or nearly so, and a cross-section at any point in an arm may be obtained in the same manner as described for the hand wheel shown in Figs. 170 and 171, and the methods used for shaping and finishing are the same. For building the rim, a wooden chuck 20½ inches in diameter will be necessary.

A board ⅞ inch in thickness and having a bar 8 inches wide and of the same thickness, well screwed to the back with wood screws will be all that is necessary for a pulley of this size. To the 8-inch bar, the iron face-plate of the lathe is screwed, and the whole turned off true in the lathe, especially the face of the chuck to which the first layer of segments is to be glued.

Strips of heavy paper are often glued between the first layer of segments and the face of the chuck, so that the rim and the chuck may be easily separated when the rim is turned and finished. The paper usually splits, allowing separation without injury to the

described for the hand-wheel pattern. The projecting ends of the arms are cut off and shaped to form a part of the outside of the rim. The internal curves of the arms at the inside of the rim are also filed and shaped down so as to form true curves without cusps or irregularities. The hub is next glued up in cross-layers as described in Fig. 172, turned out, and glued centrally on each side of the arms.

The pulley being intended for a 1¾-inch shaft, the core prints *x* and *y*, Fig. 173, should be 1½ inches in diameter, which will give ⅛ inch of metal for boring out to fit the shaft. The two core prints (Fig. 175) should be turned separate from the hubs, and loosely attached with a pin ¾ inch in diameter, and ¾ inch long, into each half hub, so that other sizes may be used for larger or smaller shafts. The two half hubs are often made loose so that they may be changed for larger or smaller hubs as may be required for different sizes of shafts. In such cases they are attached centrally to the arms as described for the core prints.

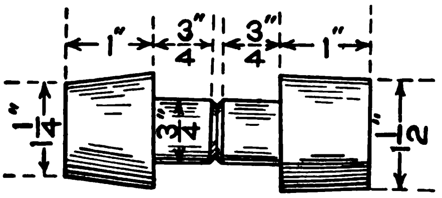


Fig. 175.

A second method in the construction of such special pulleys is as follows:

The half rim having been glued up as described, the *inside only* of this half is turned to the required dimensions and draft, sand-papered, and finished, the width of the half rim being made in this case $\frac{5}{16}$ inch less than the half of the face of the completed pattern. The arms are carefully centered and glued to this half rim; and the intervening spaces between the ends of the arms are filled in with six segments $\frac{11}{16}$ inch in thickness, which, when glued and dry, are planed, *not turned*, true and even with the surface of the arms.

A layer of segments of the regular thickness is fitted and glued on over the arms, and layer after layer continued until the full width of the face of the pattern is reached, thus building the arms directly into their place in the pattern as the rim is glued up. In turning and finishing, care must be taken not to strike the arms with the tools while turning out the inside of the outer half of the rim.

This method will be found convenient for all pulleys of moderate width of face; but as the spaces between the arms cannot be turned out, great inconveniences in reaching these places will be found when the face of the pulley is twelve or more inches in width. These spaces must be dressed out by hand.

The instructions regarding the construction of the last three patterns should be studied carefully, because the general points involved enter largely into the construction of patterns of all kinds, and especially for all work having arms with circular rims.

When pulleys of standard sizes for line shafting are manufactured in quantities, a skeleton pattern consisting of hub, arms, and an independent iron rim is used. This iron rim is of moderate width but may be used for obtaining any width of face desired.

Wooden patterns complete in themselves, as that described for Fig. 173, are used for all special pulleys on machines when the required sizes and widths, as also hubs and connections, are irregular and designed only for the special machine, so that the making of pulley patterns is important in nearly all foundries and pattern shops.

Where the iron rim is to be made, the same care is necessary in the building up of the original wooden pattern. It must be remembered that before the final casting is obtained, two shrinkages will take place; first, the shrinkage of the original casting from which the iron ring is turned, and then the shrinkage of the casting made from this pattern. In addition to this, there must be the allowance for turning the ring both inside and out and for the turning of the outside pulley rim. Suppose the pattern is to be made for a pulley two feet in diameter. The usual allowance for a single shrinkage is made by the shrinkage rule. In this case the allowance must be doubled. Thus in the above pulley, the diameter of the wooden pattern becomes 24¼ + ¼ = 24½ inches, standard rule measurements, or 24 + ¼ = 24¼ inches, shrinkage-rule measurements. As a very smooth surface, free from holes, is required, ¼ inch in diameter, or ⅛ inch all around, must be allowed for outside finish on the iron ring, and ⅛ inch for finish on the rim of the cast-iron pulley.

The outside diameter of the original wooden pattern is 24¼ + ¼ + ⅛ = 24⅝ inches, with shrinkage rule. If the final thickness of the pulley rim is to be ⅜ inch, this, with the allowance of ⅛ inch for turning out the inside of the iron ring, makes the inside diameter of the wooden pattern 23 inches, and the thickness of the wooden rim 13/16 inch, all shrinkage-rule measurements.

This wooden-ring pattern must be built up on a chuck, as described for the 20-inch × 6-inch pulley, the segments, six in number for each layer, fitted, glued, and clamped with three hand screws to each segment until a width of 6½ inches is reached.

It is then turned to the above dimensions, *without any draft*, and sent to the foundry, where it may be used for obtaining an iron rim of any required width by first ramming the sand about the pattern, partly drawing it, and then ramming again to a new level.

The casting thus obtained is then turned to the dimensions called for by an ordinary pattern; that is to say, the shrinkage-rule measurements would leave it 23¼ inches in diameter on the inside and 24⅛ inches on the outside, permitting a final finishing of the outside of the rim of the pulley to a diameter of 24 inches. When this is done, two ⅜-inch holes should be drilled near one edge of the rim and diametrically opposite each other, into which hooks may be inserted for drawing the pattern. This rim should also be turned straight and without any draft.

The arms are usually made with a wooden pattern, which has a dowel-pin hole on each side at the center for attaching the hubs that are loose, the object being to change their length and diameter to suit the width of the rim and the diameter of the shaft upon which the pulley is likely to be placed.

The arms of all pulleys should be straight because of the greater strength given to the pulley as a whole, the driving and resisting power being at least one-third greater than in a pulley of the same dimensions having curved arms. Curved and shaped arms of all kinds are now used only for ornamental purposes and for very light work.

The arms should be six in number, except for very small pulleys, when five and even four are often used. The dimensions of the arms vary greatly, depending on the purpose for which the pulley is to be used, and the weight of the machinery to be driven.

This method will be found convenient for all pulleys of moderate width of face; but as the spaces between the arms cannot be turned out, great inconveniences in reaching these places will be found when the face of the pulley is twelve or more inches in width. These spaces must be dressed out by hand.

The instructions regarding the construction of the last three patterns should be studied carefully, because the general points involved enter largely into the construction of patterns of all kinds, and especially for all work having arms with circular rims.

When pulleys of standard sizes for line shafting are manufactured in quantities, a skeleton pattern consisting of hub, arms, and an independent iron rim is used. This iron rim is of moderate width but may be used for obtaining any width of face desired.

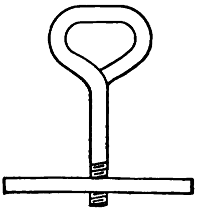
Wooden patterns complete in themselves, as that described for Fig. 173, are used for all special pulleys on machines when the required sizes and widths, as also hubs and connections, are irregular and designed only for the special machine, so that the making of pulley patterns is important in nearly all foundries and pattern shops.

Where the iron rim is to be made, the same care is necessary in the building up of the original wooden pattern. It must be remembered that before the final casting is obtained, two shrinkages will take place; first, the shrinkage of the original casting from which the iron ring is turned, and then the shrinkage of the casting made from this pattern. In addition to this, there must be the allowance for turning the ring both inside and out and for the turning of the outside pulley rim. Suppose the pattern is to be made for a pulley two feet in diameter. The usual allowance for a single shrinkage is made by the shrinkage rule. In this case the allowance must be doubled. Thus in the above pulley, the diameter of the wooden pattern becomes $24\frac{1}{4} + \frac{1}{4} = 24\frac{1}{2}$ inches, standard rule measurements, or $24 + \frac{1}{4} = 24\frac{1}{4}$ inches, shrinkage-rule measurements. As a very smooth surface, free from holes, is required, $\frac{1}{4}$ inch in diameter, or $\frac{1}{8}$ inch all around, must be allowed for outside finish on the iron ring, and $\frac{1}{8}$ inch for finish on the rim of the cast-iron pulley.

The outside diameter of the original wooden pattern is $24\frac{1}{4} + \frac{1}{4} + \frac{1}{8} = 24\frac{5}{8}$ inches, with shrinkage rule. If the final thickness of the width of the rim as well as its diameter. The length of the hub should be about two-thirds the width of the rim except in the cases of tight and loose pulleys, where the hub should be a trifle longer than the width of the rim. It may then project about $\frac{1}{8}$ inch on the sides in contact, and $\frac{1}{4}$ inch on the outside.

RAPPING PLATES.

In the description of the making of the pulley pattern, the ring serving as a binder for the hub is spoken of as a rapping plate. When a pattern is imbedded in the sand, the latter is closely compressed all about it, and slightly adheres. The moulder is, therefore, in the habit of rapping the pattern gently in order to loosen it in the sand before attempting to draw it. If the pattern is not provided with a metal plate, the moulder will drive the sharp point of a lifter into the wood and strike it alternately on opposite sides and at the same time use it to lift the pattern from the sand. This mars the pattern and will in time ruin it. The rapping plate, shown in the engraving, is a piece of thin metal $\frac{1}{8}$ to $\frac{3}{16}$ inch thick, inserted so that it is flush with the parting face of the pattern and is held by wood screws with countersunk heads. These plates are drilled and tapped for a $\frac{3}{8}$-inch screw and should be the same for all patterns in the foundry so that one set of rods can be used interchangeably. The method of using is to screw the rod into the plate and rap it gently to and fro until the pattern has been loosened, when it may be lifted. For small patterns, one rapping plate will be sufficient and this should be so placed that the hole for the lifting rod comes directly over the center of gravity of the piece. This will prevent tilting of the pattern as it is lifted from the sand. For medium sized patterns, two rapping plates should be provided, so that the pattern can be raised from two opposite sides. For still larger patterns three or four rapping plates are used; the object being to give such perfect control when drawing that there can be no tearing away of the sand.



Rapping Plate.

METAL PATTERNS.

Metal patterns are extensively used where either one of two conditions prevail: first, where the character of the work is so light and delicate that a wooden pattern could not hold together, as in ornamental castings; and second, where such a large number of castings are to be made that the wooden pattern would not last long enough to complete the work. Metal patterns may be made of iron, brass, or aluminum. The latter metal is coming into great favor because of its light weight and its freedom from corrosion by the moist sand. These patterns should be given a light coating of shellac varnish, but it is not absolutely necessary. Where iron is used, some preservative must be put upon the surfaces to protect them from rust. The best method is to warm the metal and rub it with a rag dipped in melted beeswax. This excludes the air and leaves a smooth surface so that it is easily drawn out of the sand. This, however, is not a very durable protection; the more common method is to use a shellac varnish. In order that the varnish may adhere, the metal should first be wet with a solution of sal ammoniac, and, when dry, sand-papered and shellaced.

In the small 12-inch crank pattern shown in Fig. 176, is shown a very simple *one-piece* pattern. In spite of its simplicity it requires considerable skill in shaping and in obtaining the necessary draft. The parting of the mould will be on the line C D. The piece *e*, for the main body of the pattern, should be made rectangular in form, and laid off with center lines from which the positions of the bosses *c*, *b*, and *d*, and the core print *x* may be drawn on the upper and lower sides respectively. The bosses are turned on the lathe to the required form, and given a draft of ¼ inch to 12 inches. After *b* and *c* have been glued on, the part *e* is sawed to shape, sawing close to, but not touching *b* and *c* with the saw. The thin boss *d* is next glued in place, after which *e* is filed and dressed to the required shape and even with *b* and *c*, giving it the same draft, ¼ inch to 12 inches, but in the opposite direction from the parting line C D. The rib *a* is next turned on the lathe, and one side split off on the band saw, after which it is fitted between *b* and *c*. The core prints may be turned with a small tenon on one end to fit into

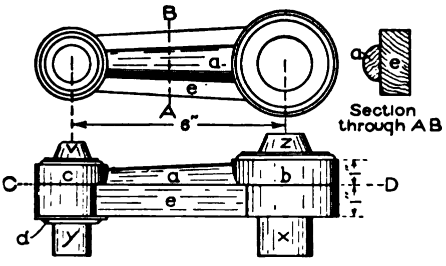


Fig. 176.

holes bored in the pattern, or they may be turned flat on both ends and nailed on. Core prints *x* and *x* must have no more draft than is given to the body of the pattern (¼ inch to 12 inches); but *z* and *z*, which will be moulded in the cope, must be ¼ inch less in diameter at the upper end than the diameter at the base.

The heavy engine-crank pattern illustrated by Fig. 177, differs but little in general construction from that shown in Fig. 176, except that, being large and heavy, it must be built up out of thin stock, as shown in the drawing. The stock is first glued up to the necessary thickness, after which it is laid out and sawed to shape as one piece, the saw table being tilted slightly to give the required draft, which in this case must not be more than ⅛ inch or $\frac{3}{16}$ inch to 12 inches.

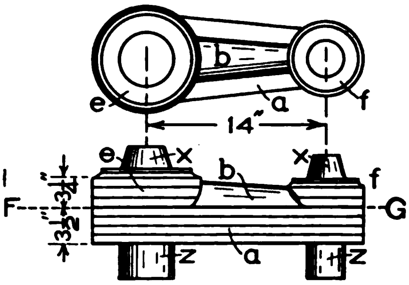


Fig. 177.

The bosses *e* and *f* are also glued up out of thin stock, the pieces being crossed so that the grain of each will be at right angles to that of the other, as illustrated in Fig. 172, after which they are turned with a draft of ¼ inch to 12 inches, and fitted to *a*.

Of the four core prints only *x* and *x* will have excessive draft, as explained in connection with Fig. 176; *z* and *z* must have no more draft than the body of the pattern. The parting of the mould, as in the former case, will be on the line F G.

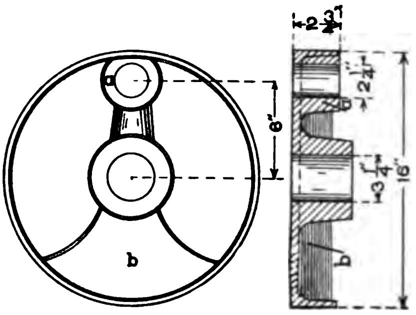


Fig. 178.

In Fig. 178, is illustrated a finished cast-iron *disc crank* for an engine of 12-inch stroke. This crank is finished on the face, on the outer edge, and on the end of the hub. It is bored out 3¼ inches to fit on the engine shaft, and 2¼ inches to receive the wrist pin. An addition of ⅛ inch must be allowed on the pattern for finish of the face, and the same on the end of the hub; $\frac{3}{16}$ inch will be sufficient to add for finish on the outer rim, making the diameter of the pattern $16\frac{3}{16}$ inches, and the thickness of the disc $\frac{9}{16}$ inch. A sectional view of the pattern is shown in Fig. 179.

The disc for this pattern must be made of two thicknesses of sectors, six in number for each thickness, which, after being fitted, glue-sized, and glued together, are planed off true on both sides, and glued on each other so as to break joints, as shown in Fig. 180. When dry, the disc thus obtained is sawed to a diameter of $16\frac{1}{2}$ inches and glued to the wooden chuck on the iron face-plate of the lathe with small sectors of thick paper between, or else glued to small blocks on the chuck, from which, after turning, it can be cut as illustrated in Fig. 168. The rim is now built up on the disc out of segments $\frac{3}{8}$ inch or $\frac{1}{2}$ inch in thickness, as directed for the 20-inch pulley (Fig. 173), with not less than six segments to each course. The hub is glued up as described, and, after gluing on the disc, the whole is turned to the required size and shape.

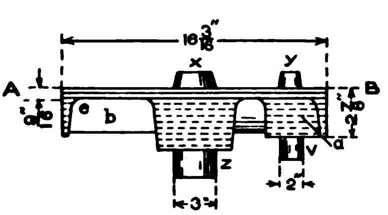


Fig. 179.

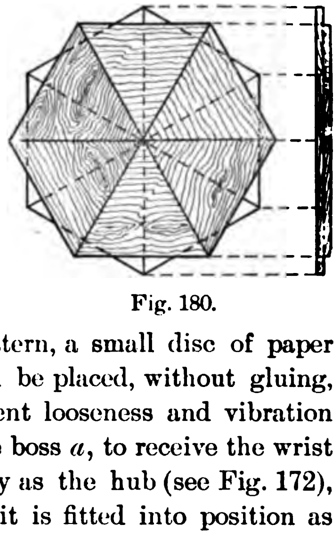
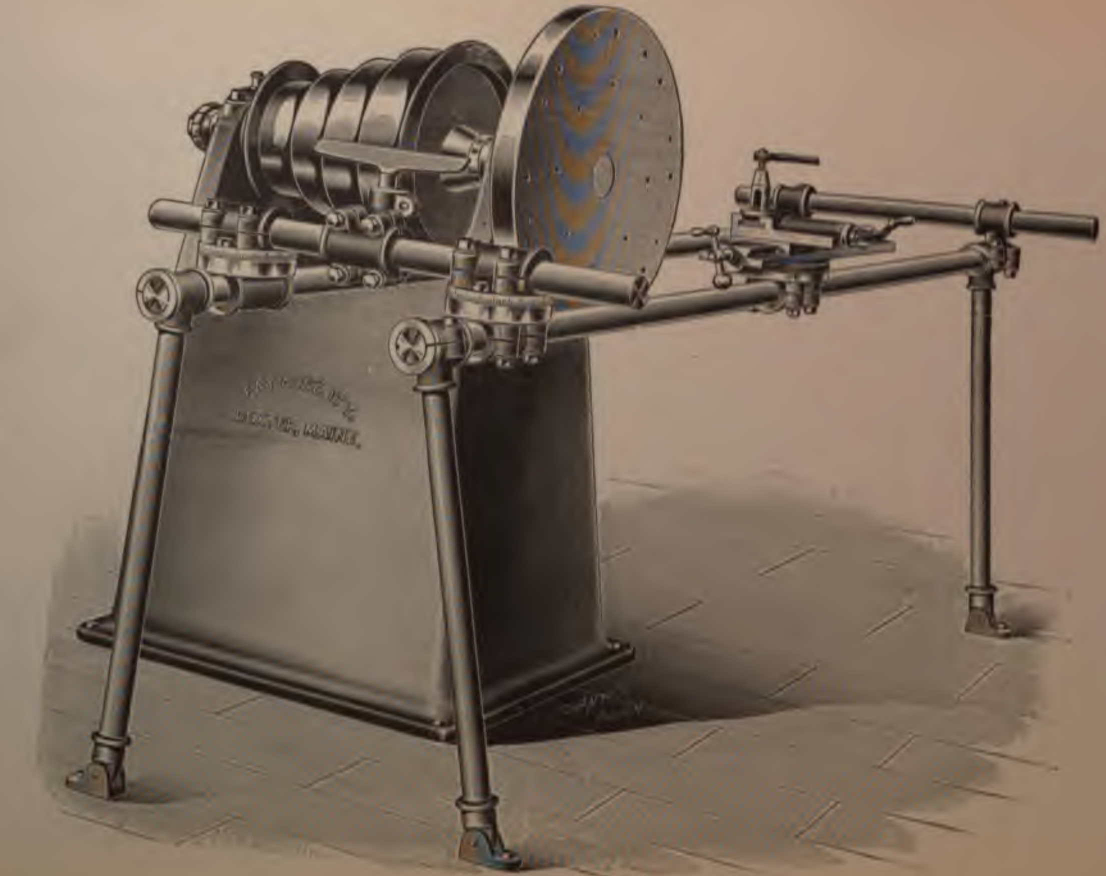


Fig. 180.

In the case of this disc-crank pattern, a small disc of paper (or a block, if blocks are used) should be placed, without gluing, under the center of the disc, to prevent looseness and vibration while being turned in the lathe. The boss *a*, to receive the wrist pin, must be glued up in the same way as the hub (see Fig. 172), and turned on the lathe, after which it is fitted into position as indicated in Figs. 178 and 179. The counter-weight *b* is next shaped from a single piece, or it may be glued up of several thicknesses of $\frac{1}{2}$-inch stock. In sawing this block to shape, the band-saw table should be tilted so as to give it a draft of $\frac{3}{8}$ inch to 12 inches. Give the inside of the rim, the hub, and the boss *a*, the same draft, but the outside of the rim should not have a draft of more than $\frac{1}{8}$ inch to 12 inches.



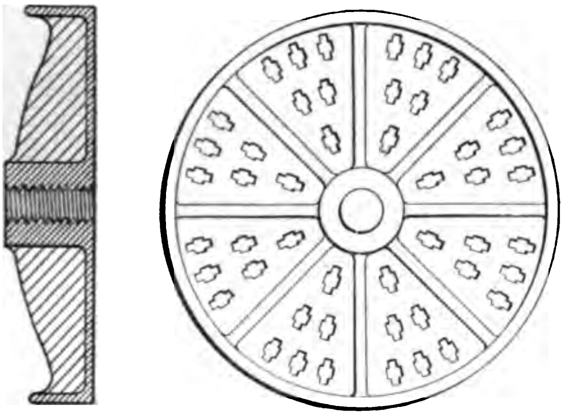
FACE PLATE LATHE.
Fay and Scott

or a rag dipped in the hot water of the outer glue-pot and wrung out nearly dry, care being taken not to wet any part of the pattern more than can possibly be helped, after which it must at once be wiped dry.

These leather fillets will be found more pliable and more easily placed and rubbed into position if the glue used is first allowed to cool slightly. Very hot glue stiffens and crinkles the leather, causing it to work hard.

FACE PLATE.

It is sometimes advisable to use cores even if it is quite possible to construct the pattern so that it would core its own holes. This is the case where it is desired that the faces of the casting and the holes shall be smooth and as true as possible without expensive machine work. The finished face-plate of an engine lathe illustrated in Fig. 182 is a good example of such work.



a. Fig. 182. *b.*

It will be readily seen that the pattern for this casting could be put in the sand and withdrawn from the mould, leaving the sand standing where the holes are located.

The trouble that arises from this method is due to the fact that when the metal is poured and allowed to flow about the fragile projections that are left to form the holes, the sand washes away, so that the holes in the casting are irregular and much smaller than those in the pattern. For these reasons the holes should be cored, as the core sand is firm and better able to resist the washing action of the flowing metal.

The patterns for such a face plate, a cross-section of which is shown in Fig. 183, should be made as follows: The allowance for finish on the face of the casting should be not less than $\frac{3}{16}$ inch, and the same should be added to the diameter and also to the end of the hub. Having thus determined the thickness and size of the pattern, the disc should be built up of from four to sixteen sectors, according to the size of the plate. If the diameter is between 24 and 42 inches, sixteen sectors should be cut out, each filling an arc of 45°, so that when eight are placed edge to edge they will complete the circle. The thickness should be a little more than one-half the completed thickness of the pattern disc, and they should be laid up so as to form two layers, breaking joints with each other as shown in Fig 180. When the disc is formed, the hub should be first glued in position, this also being built up of pieces glued together, and the whole attached to a large wooden chuck and iron face-plate of the pattern lathe in the same manner as described for the disc-crank (Fig. 178). The rim is next built upon the disc in the same way as has been described for former patterns. If the face plate is very large, the segments may be $\frac{1}{2}$ inch or even $\frac{5}{8}$ inch in thickness, and to avoid end wood, eight, twelve, or even sixteen, segments may be used for each layer according to the diameter of the rim.

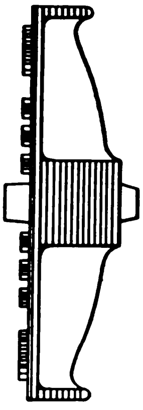


Fig. 183.

The pattern now consists of the disc with the rim and hub in position, but larger than they should be. It is, therefore, placed in the lathe and carefully turned over its whole surface, each part and thickness being brought to the shape and dimensions of the completed pattern, care being taken to turn in a fillet of $\frac{1}{4}$ inch to $\frac{1}{2}$ inch radius, depending on the size of the required casting, in the angles connecting the rim and the hub with the disc. Next put in the ribs; it is not necessary to form these out of built-up material, for each may be cut from a single piece. They should be carefully fitted to form a close joint with the rim, the disc, and the hub, before they are glued in position. When this is done, all angles formed by the rim, ribs and hub with each other should be carefully filleted.

After the fillets are in position, it remains to provide for the coring of the holes. This is done by first laying out upon the face of the pattern the location and size of the holes. It is upon the points thus located that the core prints are placed. Before this is done it must be decided which side of the casting is to be made uppermost.

Where a large, flat surface is to be given a finish, it is desirable that the metal should be as clean and free from sand and blowholes as possible. As the iron has a greater specific gravity than the sand of the mould, all particles of sand that may be washed away and all gases generated, rise to the surface of the molten metal. Those imprisoned by the cooling of the iron form the dirt and blowholes that disfigure the completed casting. In a casting such as the face-plate under consideration, it is desirable, then, that the face should be upon the lower side when the metal is poured. For the sake of convenience in setting the cores, the prints are put upon the face and make their impress in the sand of the drag. They should be glued and nailed in position after the pattern itself has been sand-papered. The core prints for the hole through the center are also put on in the same way.

PIPE CONNECTIONS.

Many patterns which at first may seem to be quite formidable, will, after a little study, resolve themselves into a few very simple parts, nearly all the work for which may be done in the lathe. Of this the tee pipe connection shown in Fig. 184, is a good illustration.

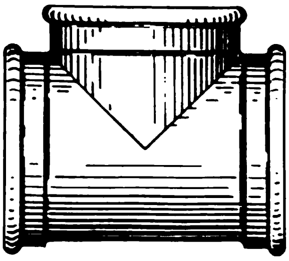


Fig. 184.

A sectional view of the casting, threaded and having a pipe screwed into the right-hand end, is shown in Fig. 185.

The completed pattern for this casting is illustrated in Fig. 186, with its core prints *a*, *a* and *a*, and must be parted as shown in Fig. 187. The entire pattern may be made at a single turning as illustrated in Fig. 188. The preparation of the wood for this pattern is similar to that described for the pattern of the brass bearing, Fig. 150; the two halves having the necessary dowel pins inserted, and glued together at the extreme ends only.

When there is not time for the glue to dry, all such *parted* work may be held together while being turned, by having staples driven into the ends as shown in Fig. 188. Indeed, for all large and heavy work this method is to be preferred; two, and even four, staples being used in each end as the size of the work may demand. When the turning is completed, it is only necessary to cut a V-shaped opening into the two halves of *e*, into which the part *f* is fitted and glued. When the glue has set and is sufficiently dry, the joint may be further strengthened by nailing, or by inserting and screwing a thin metal connecting plate flush with the parting side of each half of the pattern. This, however, will be necessary only when patterns are large and heavy, or when unusual strength is required.

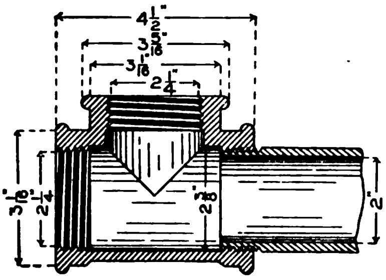


Fig. 185.

The core box for this pattern, as will be seen in Fig. 189, is the usual half box and is made by working out the box in one piece, long enough to make the two parts *a* and *b*. The two parts are united by cutting a V-shaped opening in the part *a* and fitting *b* into it in the same way as described for the pattern. The whole is then glued and screwed to the board *c*, and the two triangular blocks *d* and *d* are glued in the angles to add strength to the completed box. In case the pattern is for a very small pipe, 1½ inches or under, the part *b* may be abutted against the side of *a*, as shown by the dotted line, and the side of *a*

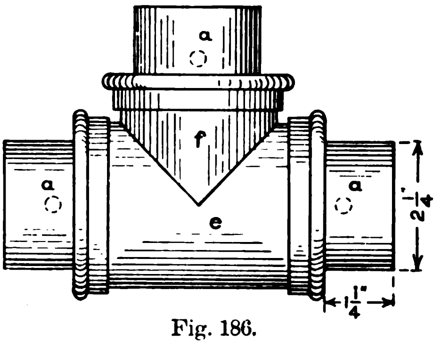


Fig. 186.

at *e* cut away to the same curve as *b*, giving the same results as in the former method.

The pattern for the 2-inch elbow, Fig. 190, is another illustration of how such work may be simplified, and time saved, by doing the greater part of the work in the lathe.

As these elbows are usually cast in large numbers, the pattern should be made double as shown in Fig. 191. To construct the double pattern, a ring is first turned like Fig. 192, a cross-section of which is a semicircle as shown in the lower right-hand corner of the drawing. This ring is cut into quarters, and the four pieces *e*, *e*, *e* and *e* make the quarter turns for the two halves of the double pattern.

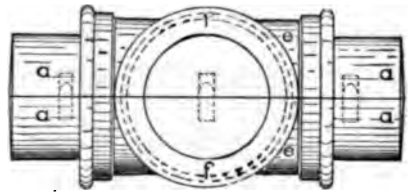


Fig. 187.

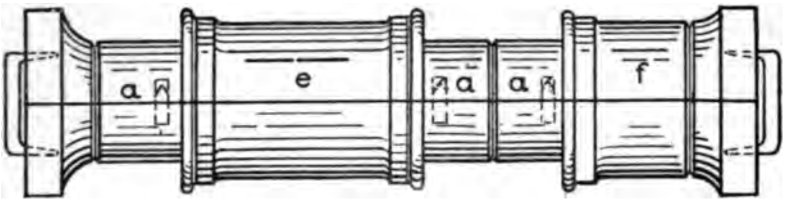


Fig. 188.

The ends, including the core prints and connecting tenons, are turned in one piece as shown in Fig. 193, the stock for which is prepared, with the inserted dowel pins all in position in the same manner as described for the tee pattern, Fig. 188. The quarters, *e*, *e*,

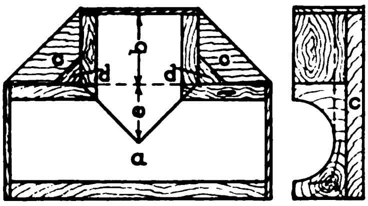


Fig. 189.

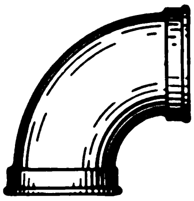


Fig. 190.

e and *e* are clamped together two and two, and the ends carefully bored to receive the tenons which are then glued in position and further strengthened by a wood screw as shown in Fig. 191.

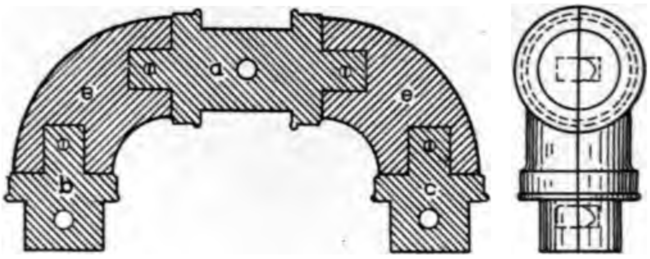


Fig. 191.

In Fig. 194, the core box for this double pattern is shown, and as will be seen the most difficult part of the work can be done in the lathe. Fig. 195 shows two pieces jointed and clamped together which must be screwed to the face-plate of the lathe and turned out to make the two corners *c* and *c*. The three straight parts *d*, *d* and *d* are worked out in one long piece and afterwards cut to the required lengths, after which the five pieces are glued and screwed to the board *a*. The ends *e*, *e* are next put on and the required half core box is complete.

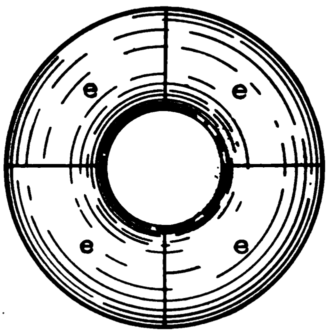


Fig. 192.

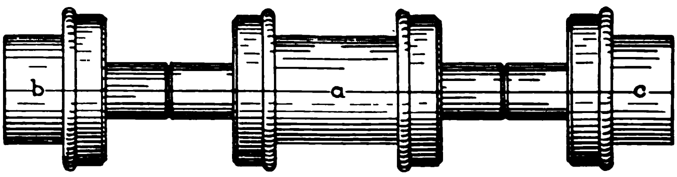
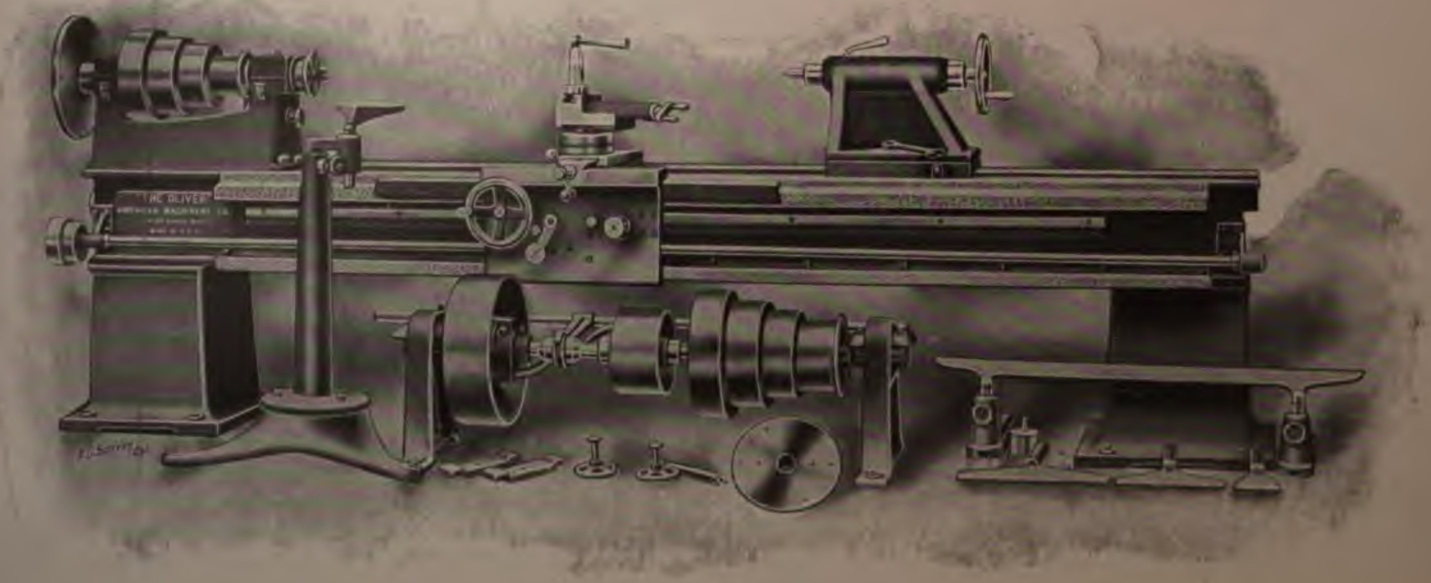


Fig. 193.

Another reason why the pattern for pipe elbows should be made double is that otherwise the core prints would require to be made of great length in order to balance, sustain, and keep the heavy core



WOOD LATHE.
Oliver Machinery Company.

in position; the tendency being to sag in the middle, or float on the molten iron, and thus make the upper side of the casting too thin, all of which is avoided in the double pattern.

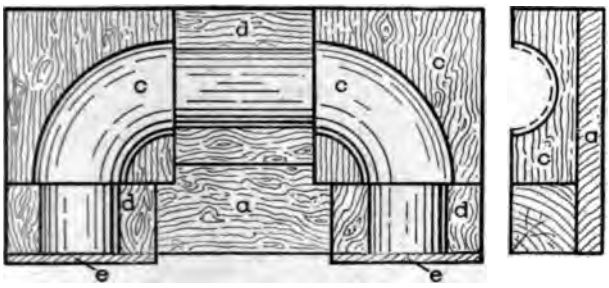


Fig. 194.

A pattern for the return bend, Fig. 196, can be built up and constructed in the same manner as described for the elbow; the semicircular returns, not only for the pattern, but also for the core box, being turned in the lathe, together with the ends and core prints for the pattern. As there will be no middle support for the core in this case, the core prints must be made, as shown in the half pattern, Fig. 197, of sufficient length to balance the heavy semicircular core, and also to keep it in its true position in the mould.

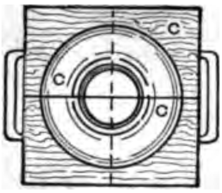


Fig. 195.

The small wood lathe chuck, a vertical section of which is shown in Fig. 198, will serve as a simple illustration of the long

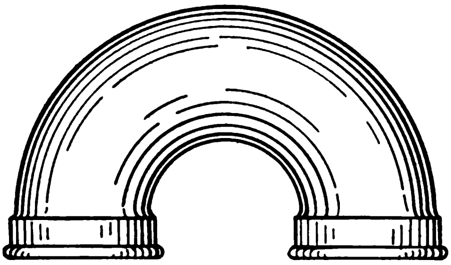


Fig. 196.

core print and *balanced* core. The casting must be counter cored; that is, the cored opening must be enlarged at the forward end, adding to the size and weight of that end of the core, which, as will be seen, has no support except that afforded by the extra length of the core at the opposite end. The pattern for this chuck is shown in Fig. 199, and the core print must have a length at least twice as great as the depth of the hole in the chuck. The core box is shown in Fig. 200.

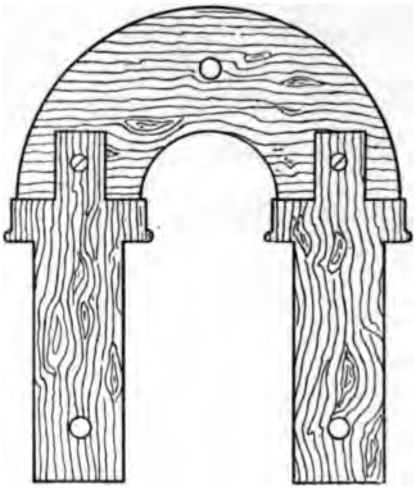


Fig. 197.

When pipes or cylinders are of moderate size with deep flanges for bolting together (Fig. 201), the flanges for the pattern are turned out of a separate disc as shown in Fig. 202, and firmly glued and nailed on over the core prints and against the ends of the main body of the pattern; the core print being made of sufficient length to receive the flange. A recess is sometimes turned in the inside end of the core print to receive the inner edge of the flange as shown in Fig. 203, and into which it is fitted, thus adding greatly to the strength of the joint.

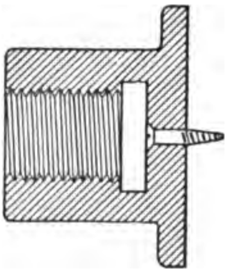


Fig. 198.

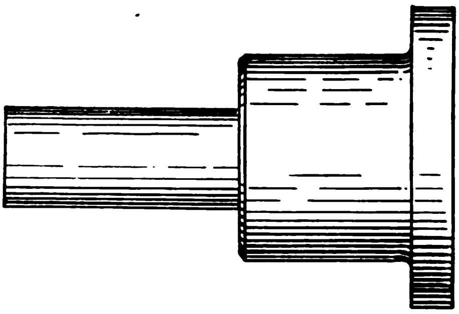


Fig. 199.

The flanges should be made by gluing up *three* pieces and crossing the grain of the pieces so that the grain of each will run at right angles to that of the other. In gluing pieces together for thin discs, *three* pieces should always be used. *Two* thin pieces glued together will always warp.

A still better and stronger method of making large flanges is to cut out segments, five or six for each course, and fit and glue up on a chuck and face-plate in the same way as described for the hand wheel rim (Fig. 168); two or three courses being used for each flange, which after being turned to the required size and form, the ring is sawed in two with a very thin saw, and each half fitted into place on the pattern. The main body of the pattern is glued up out of strips as shown at *a*, Fig. 204, and for turning, the two halves are held together by means of staples as shown in Fig. 188.

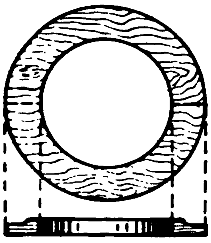


Fig. 202.

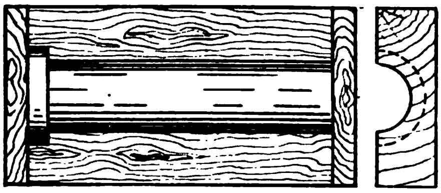


Fig. 200.

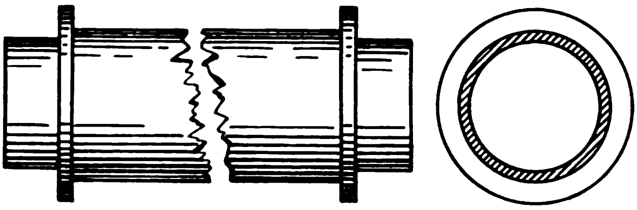


Fig. 201.

A short temporary block is then fitted and glued into the opening in each end to receive the lathe centers. A staple plate, similar to that illustrated in Fig. 205, may be used to great advantage for all work of this kind, making as it does, a secure connec-

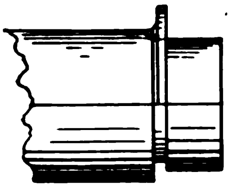


Fig. 103.

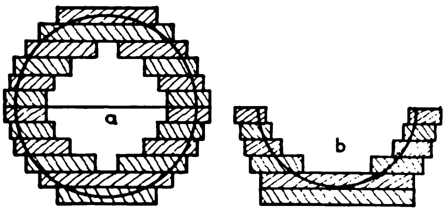


Fig. 204.

tion and doing away with the otherwise temporary center block.

The method of constructing the core box for this or similar patterns, is shown at *b*, Fig. 204.

Tees, elbows, and other bends and connections, when large, are built up in a similar way, thus making a lighter, and also more durable pattern.

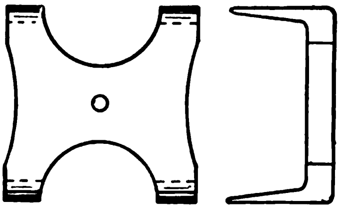


Fig. 205.

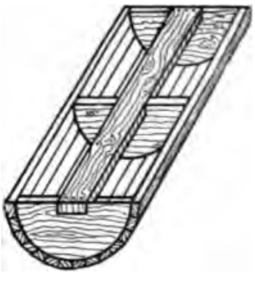


Fig. 206.

For large cylinders, a much lighter and simpler method of constructing the pattern is shown in Fig. 206. For each half of the pattern the two end discs, and the middle semicircular disc are connected together by a strong center bar, which is fitted, glued and screwed into each, serving not only to strengthen the pattern, but also to hold the connecting dowel pins. When the two halves of the pattern are clamped together (with staples) it serves also as a secure means of centering in the lathe.

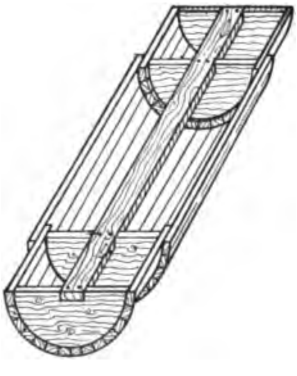


Fig. 207.

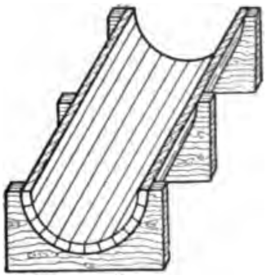


Fig. 208.

The staves forming the body of the cylinder are fitted and glued to each other and screwed, or nailed to the discs. After the

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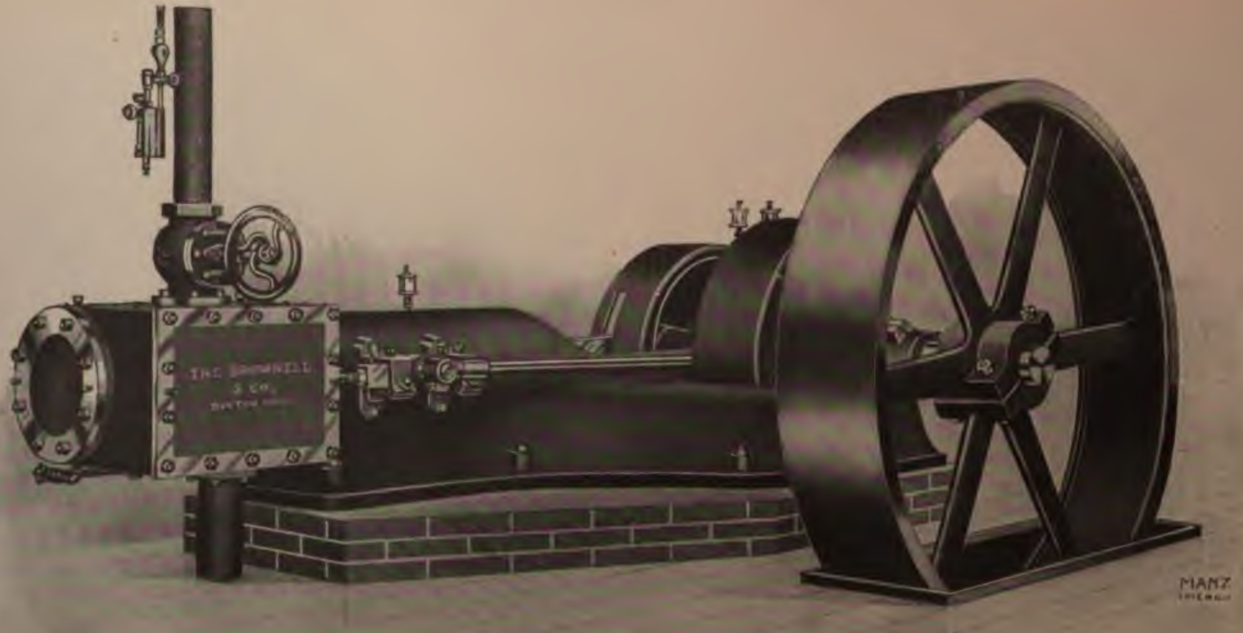


SELF-CONTAINED AUTOMATIC ENGINE.
The Brownell Company.

cylinder has been turned, the core prints and flanges are built up and turned separately, and glued and screwed to the ends of the cylinder from the inside of the end discs.

Fig. 207 illustrates still another and better method of building up the cylinder and core prints in one piece and completing the whole at a single turning. The core prints, as shown, are staved up first, and then the staves to form the body of the pattern are fitted, glued and screwed, or nailed, over the ends of those which form the core prints. Should the body of the cylinder be long, one, two, or more middle semicircular discs must be used.

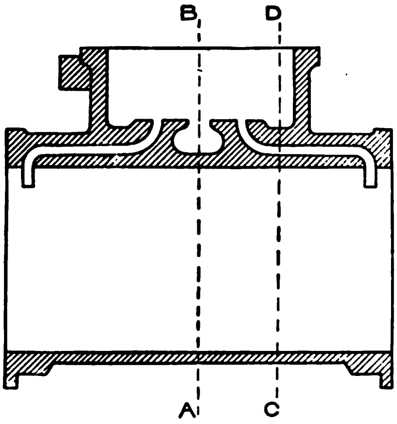


Fig. 209.

A similar construction for the core box is shown in Fig. 208, and is to be preferred to all others because if laid out and built to the exact size, the labor required to reduce the staves to a perfect semicircle of the required radius is very little.

ENGINE CYLINDER.

The slide-valve engine is built in a great variety of forms. Fig. 209 represents a sectional view of the cylinder of a very common type. At *e* Fig. 210, we have a cross-section through the steam chest and exhaust port at *A B;* and at F, a cross section at *C D* through the steam port.

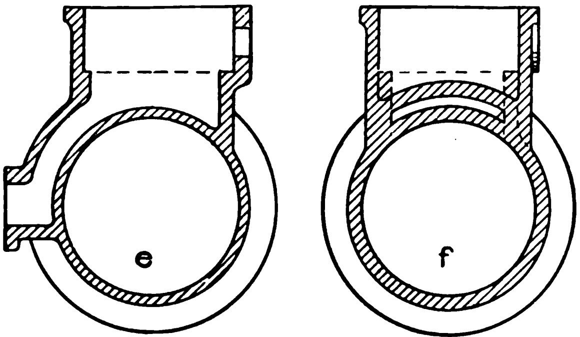


Fig. 210.

When the cylinder is small (ten inches or under in diameter) the pattern is usually built up solid, but if more than ten or twelve inches in diameter it should be built of staves, as shown in Fig. 211.

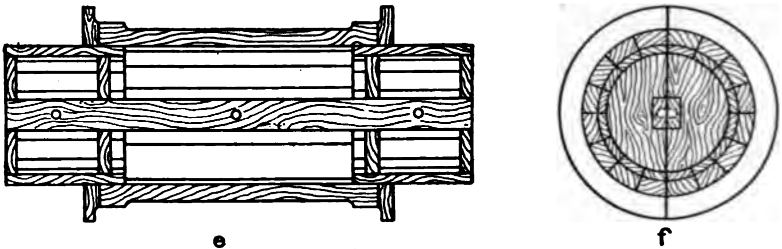


Fig. 211.

When the size is thirty inches or over, a loam mould is usually made as will be fully described in the section on Foundry Work. The size limit, however, varies greatly in different foundries.

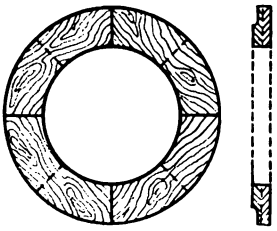


Fig. 212.

The construction of the pattern is illustrated in Fig. 211, and needs no description here, it being the same as already given for Fig. 207. The flanges, however, should be built up of segments of two or three layers each as shown in Fig. 212. After gluing up to the necessary thickness to make the flange, it is sawed in two halves, jointed and carefully centered on a wooden chuck and turned to the dimensions required.

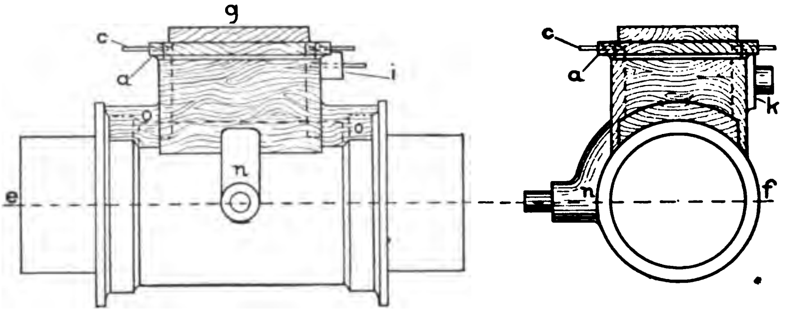


Fig. 213.

The centering must be done with accuracy, or one half of the flange ring will be larger than the other. The steam chest is next built and fitted centrally on the upper half of the cylinder pattern as in Fig. 213. The projections *a*, *a*, which give the extra width of metal for the bolts of the chest cover are left loose, being kept in place by long wires or dowel pins as shown at *c*, *c*, so that they can be withdrawn separately from the mould after the main part of the pattern has been taken from the sand. These four strips should be recessed into the corners of the chest one quarter inch, as shown by the dotted lines, to prevent them from being rammed out of place after the dowel pins are taken out. The boss *i* for the valve-rod stuffing box, and also the boss *k* around the steam-pipe opening, must be loose so as to be taken out of the mould after the pattern has been removed.

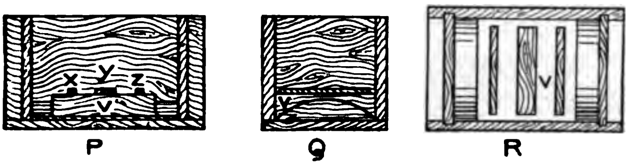


Fig. 214.

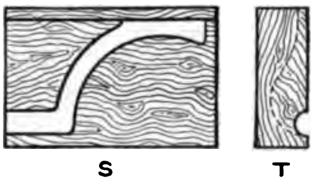


Fig. 215.

The pieces *o*, *o*, at each end of the steam chest, which form a thickness of metal over the steam ports, are next fitted in place, as also the exhaust passage *n* which must be parted on the line of parting of the two halves of the cylinder pattern.

The main core box for the cylinder is made in the same way as has been already described for Fig. 208. The steam-chest core box is shown in Fig. 214, in which P is a side view, one side of the box being removed to show the valve seat *v*, and the core prints *x*, *z*, and *y*, which form recesses in the core, into which the upper ends of the two steam inlet cores, and the central exhaust passage core are placed. Q is an end view of the box with one end removed, and R is a view looking into the box from above.

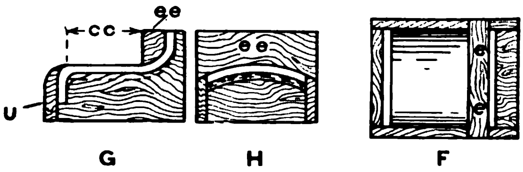


Fig. 216.

For the core forming the exhaust passage, two half core boxes, one right and one left, will be necessary. One half of this box is illustrated at S, Fig. 215, as also a sectional view at T. The dotted lines show the manner in which the passage is widened to retain the full size of the opening throughout.

Only one core box will be needed for the two steam ports. Three views of the box are given in Fig. 216. At G one side is removed, giving a side view of the construction of the box. H shows a cross section through G with the end *u* removed, and F is a view from above. The core is swept off on the upper side for the length of *c c*, and the bar *e e* as well as the end *u* must be movable so that the core can be taken from the box. Both ends of the core change from circular into straight parts just at the entering of the cylinder, and at the entering of the steam chest.

The entire set of patterns are simple and easy of construction, if carefully made drawings are furnished to work from; the time and labor required, depending entirely upon the size of the cylinder.

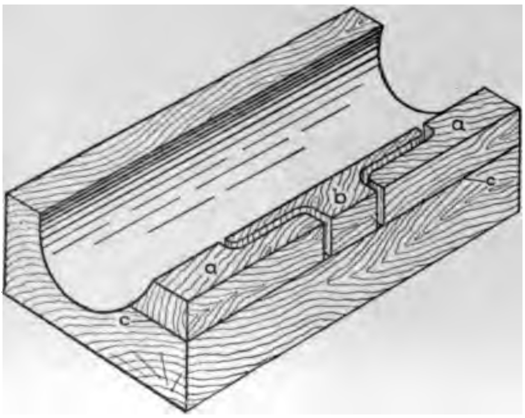


Fig. 217.

In some slide-valve cylinders, the steam chest is cast separate and bolted to the cylinder, thus affording free access to the valve seat *v*, and a better opportunity for finishing and fitting. In this case the main cylinder core and the two steam inlet cores are made together in the same box, as illustrated in Fig. 217, in which one side of the core box is cut away to a depth of one half of the length of the steam port openings, or to the line *c*, *c*, which must be just one half of the inside width of the box as shown at *H* and at F, Fig. 216.

The part which has been cut away is replaced by the three blocks *a*, *a* and *b*, which are shaped to give the required size and form to the steam-port cores.

These blocks are fastened by dowels, loosely, to the main part of the core box, and after the core has been rammed up, the whole box and core is turned over on its face and the main part of the box is lifted off, after which the two loose blocks *a* and *a* can be drawn away endwise and the block *b* can also be lifted out with ease.

GLOBE VALVE.

The globe valve, shown in section in Fig. 218, is a good illustration of a pattern in which, while the outside may be very simple, the inside is intricate and requires considerable practice and skill to so contruct the core boxes that the core can be withdrawn from them, and at the same time give uniform thickness and strength to all parts of the shell and to the internal partitions.

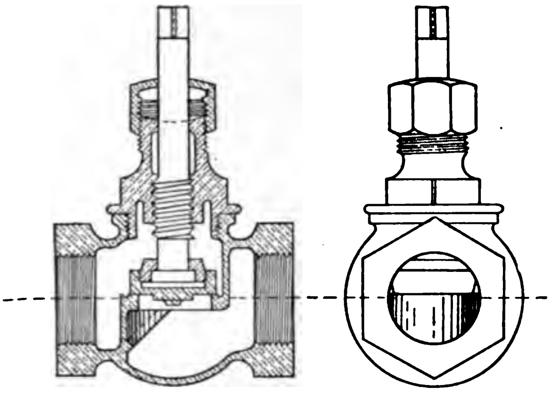


Fig. 218.

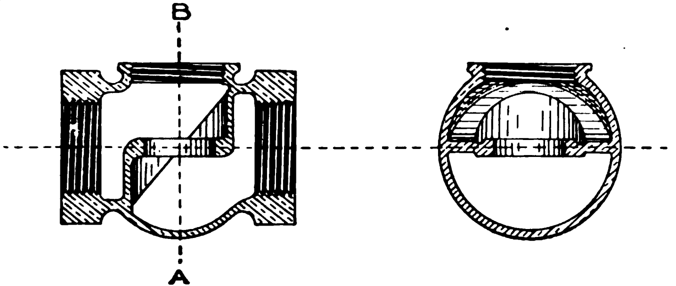


Fig. 219.

In Fig. 219 is shown a sectional view of the body of the valve, and in Fig. 220 an illustration of the completed pattern, from which it will be seen that almost the entire work, with the exception of fitting, placing the dowel pins, and forming the two hexagonal ends, is done in the lathe. The construction is shown in the sectional illustration of the half-pattern, Fig. 221. The wood for the two halves must be of sufficient length to allow for gluing at each end or for the insertion of iron staples. In turning, the greatest care must be taken to center exactly on the parting line of the two halves.

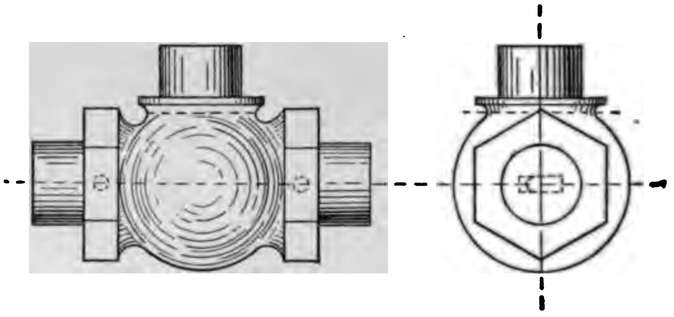


Fig. 220.

A carefully shaped template, such as is shown at *a*, Fig. 221. must be used in turning. This template may be made of a thin piece of wood, but for all purposes for which templates are required in pattern making, and their use is necessarily very great, sheet zinc is the best material. It is soft, and easily cut and filed, and does not dull the cutting tools so much as other metals

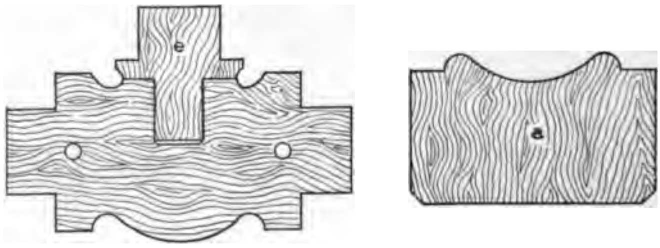


Fig. 221.

Before marking out the template, that the lines may be more readily seen, it should be cleaned with a piece of emery cloth and have a dark coating of the following solution. Dissolve an ounce of sulphate of copper in about four ounces of water and to this add one teaspoonful of nitric acid. Treat the surface of the zinc with this solution, rubbing on with a piece of waste. A thin coating of copper will thus be given to the zinc (also to steel or iron). When applied to finished surfaces they should be rubbed dry, as iron or steel will be rusted.

When the curves of the template will allow of sawing, the zinc template is easily shaped by placing a piece of zinc of the necessary size between two boards, and nailing them together. The required shape having been drawn on the upper board, the whole may be sawed to the form required on the band saw or scroll saw, but preferably on the latter, with a fine tooth narrow saw blade which will give a smoother edge to the zinc. If the boards are firm, the metal will offer no resistance whatever to the saw, nor will the saw be perceptibly dulled. For small curves, lay the zinc on a piece of hard board, and with a pair of sharp pointed dividers the zinc can be scratched half way through its thickness, then by turning it over and placing the dividers in the same center, the other side may be cut in the same way, or so nearly through that it will break off. This affords a truer and more uniform curve than can be obtained in any other way. The legs of the dividers must be stiff and firm so as to be entirely free from vibration. After cutting, the sharp edges of the zinc may be dressed with a fine double-cut file, or better with fine emery cloth or sand paper rolled over a wooden holder.

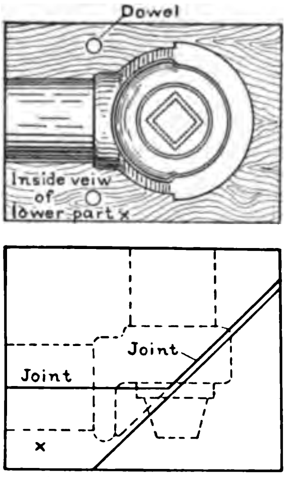


Fig. 222.

The lathe should always be stopped when testing the work with the template, and great care must be taken to make the two ends of the pattern symmetrical.

When the turning is nearly completed the template itself may be tested by reversing the ends. If not true it should be filed to the proper shape as shown by the drawing.

The branch *e* must be turned in the same way as described for the main part of the pattern which is pared off, or planed off in a large pattern, to the exact size of the base of the branch, and when the pattern is large and heavy, one or two wood screws should be used in the tenon of the branch to assist in keeping it in place.

In all small and moderate-sized valves, the flanges are hexagonal in shape as shown in Figs. 218 and 220. The core for a globe valve is made in two parts, and the core box for each part must be made in upper and lower half, making four parts to the core box. This is necessary in order to allow for the removal of the core from the boxes. The internal shape of the boxes are difficult to illustrate on paper, but if the drawings given in Figs. 222 and 223 are carefully studied in connection with the sectional views of the valve shown in Fig. 219 their shape and construction should be readily understood.

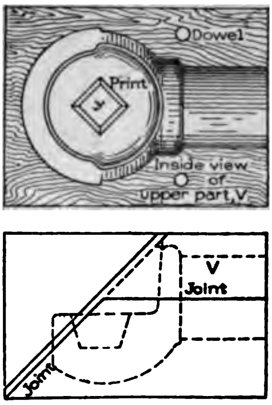


Fig. 223.

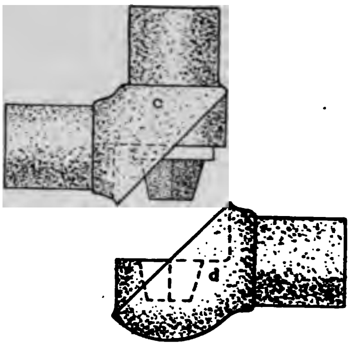


Fig. 224.

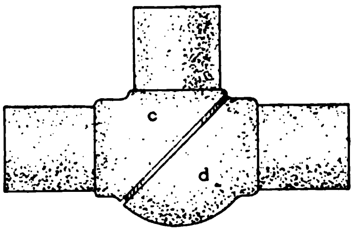


Fig. 225.

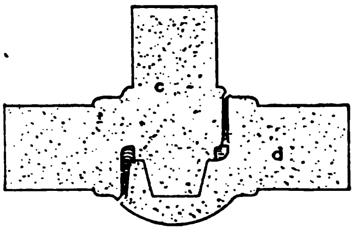
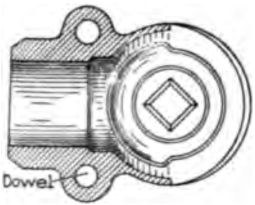


Fig. 226.

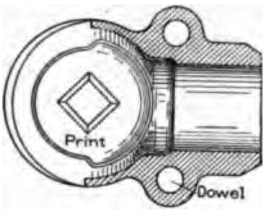
Three additional illustrations of the core as made in these boxes are shown in Figs. 224, 225 and 226.

In Fig. 222 there are two views of the box in which the upper part C of the core shown in Fig. 224 is made. This box separates along the two lines marked "Joint" (Fig. 222) and, as will be readily seen, allows the core to be easily removed when the box is opened. The lower part *d*, Fig. 224, of the core is made in the box shown in Fig. 223. The part *c* has a square tenon which fits into the mortise in the part *d*. This mortise is made in the core by means of the print marked Y in Fig. 223, and as will be seen by Fig. 224, this core tenon and mortise will bring the two parts of the core into perfect alignment when they are pasted together.

In Fig. 225, we have an outside view of the completed core and in Fig. 226 a sectional view through the middle of the core, lengthwise; from which the necessity for the tenon and mortise connection will be readily understood, this being the only connection between the two parts of the core. In working out the core boxes it is well to use templates which can be formed and made from the drawings furnished. The templates will aid in getting the proper shapes, and leaving a uniform amount of metal in all parts of the case.



Inside view lower part X



Inside view of upper part, V.

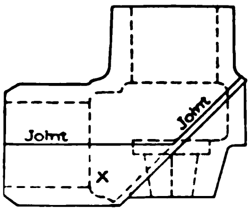


Fig. 227.

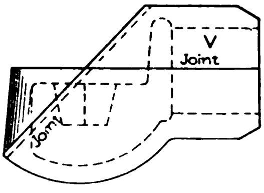


Fig. 228.

Figs. 222 and 223 illustrate the common wooden core box, but to insure uniformity, and because of the necessary wear and fragile character of wood for boxes of this kind, these core boxes should be made of metal. The wooden pattern for the metal core-box must then have an allowance for double shrinkage, and to avoid excessive weight, the box is made in the form shown in Figs. 227 and 228. In this form all unnecessary metal is removed and the connecting iron dowel pins are placed in lugs or thin outside projections as indicated.

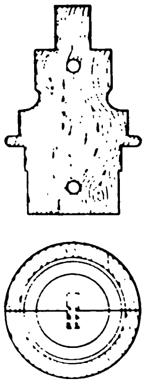


Fig. 229.

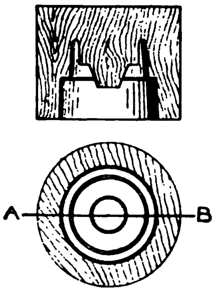


Fig. 230.

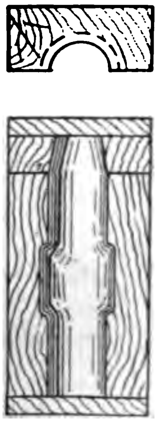


Fig. 231.

Fig. 229 illustrates the pattern for the stuffing box and bonnet of the valve, with core print turned on each end, which, like the main pattern of the valve must be parted, or made in two halves. Two core boxes are necessary to make the core for this part of the valve.

From Fig. 230 it will be seen that the core box for the lower end of the core can be turned out on the lathe by using a template of the required shape. For the upper part or stem, the half box shown in Fig. 231, is all that is necessary. By examining the two core boxes, Figs. 230 and 231, it will be seen that here again we have recourse to the tenon and socket form of construction for uniting the two parts of the core which are shown pasted together in the completed core, Fig. 232. The nut for the bonnet is shown in Fig. 233, and the pattern, which is hexagonal, should be so made as to form its own core, as indicated by the dotted lines in the drawing. Fig. 234 shows the pattern for the valve and also the pattern for the valve nut, each of which will form its own core, and Fig. 235 is an illustration of the pattern for the valve spindle.

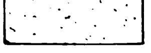
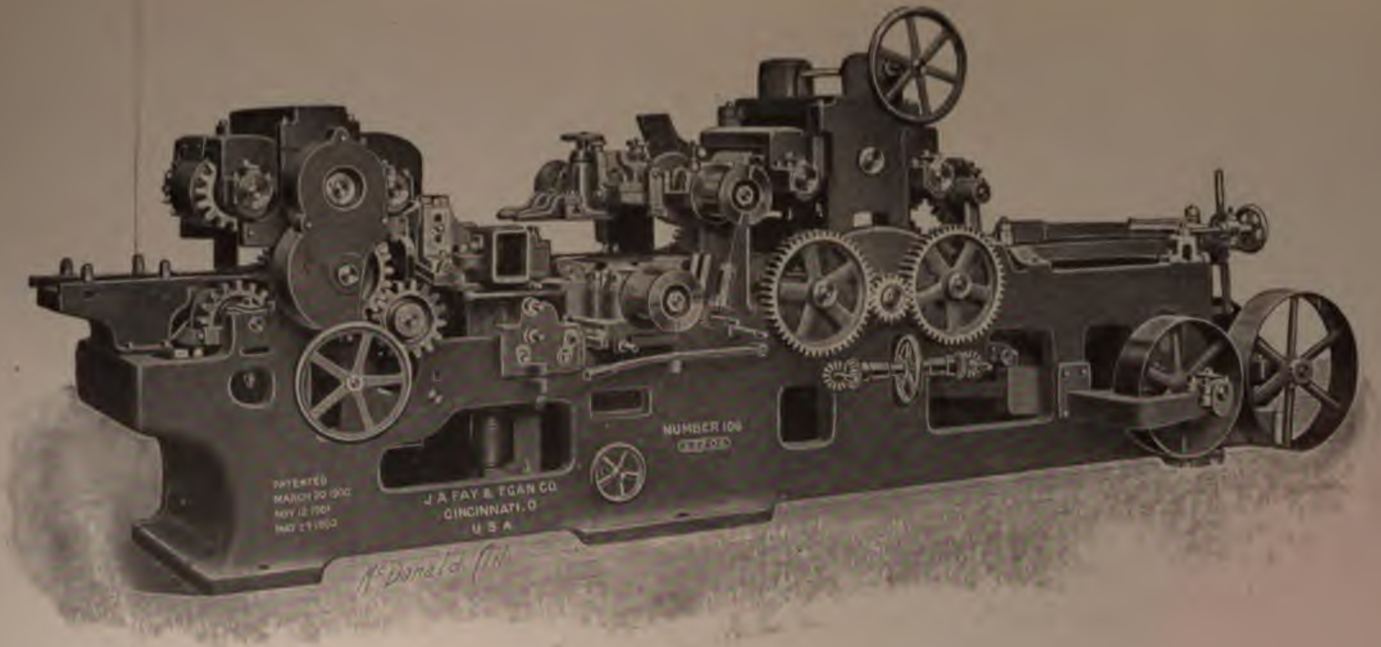


Fig. 232.



FLOORING MACHINE.

J. A. Fay and Egan Co.

GEAR WHEEL PATTERNS.

In this special class of pattern work, the greatest accuracy and care must be taken, not only in building up the rim of the wheel, but in fitting and placing on the rim the blocks, out of which the teeth are to be formed, and most of all in laying out the teeth regularly and accurately on the tooth blocks. A pattern for a gear wheel, whose teeth are carelessly made is almost worthless, the time lost in chipping and filing, for the purpose of correction, being too great to allow the use of such a pattern.

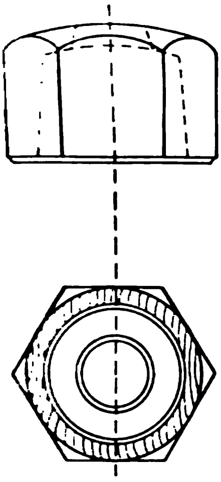


Fig. 233.

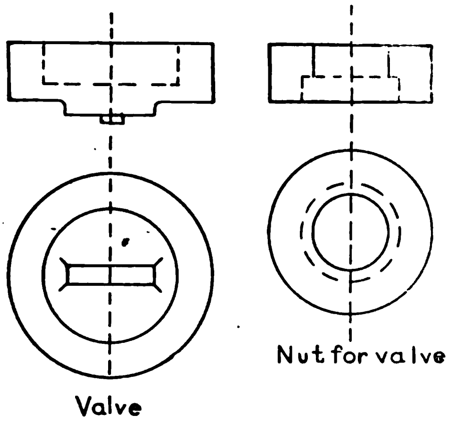
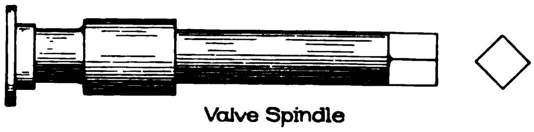


Fig. 234.



Valve Spindle

Fig. 235.

To insure greater accuracy and smoother running gears, it is now the custom in many shops to have the wooden pattern made in the form of a blank, (without teeth) from which a metal pattern is cast.

This cast pattern is turned up and placed in the milling machine where the teeth are cut and spaced with accuracy and to the exact form of tooth required. This metal pattern is used without *draft*.

This method of making gear patterns, however, is expensive, and is used only when many wheels are to be cast of the same size and number of teeth from the same pattern, and, as in the case of pulleys, the wooden pattern is still used for all special sizes of gears.

For these wooden patterns we shall now give a few hints as to the best methods of construction. As the form of the tooth used by the draftsman will play no part in the construction of the pattern, we think it would be out of place here to enter into a discussion of the relative merits of the single curve, double curve, or other form of tooth.

The single curve or involute tooth, however, has the great advantage of being the only form of gear which can be run at varying distances of axes, and transmit an unvarying velocity and amount of power. The common contention that two gears will crowd harder on their bearings when the single curve, or involute form is used, has not been proven in actual practice. The practical methods for obtaining the curves for either the involute or for the epicycloidal tooth, the two forms in most common use, are taken up in Mechanical Drawing.

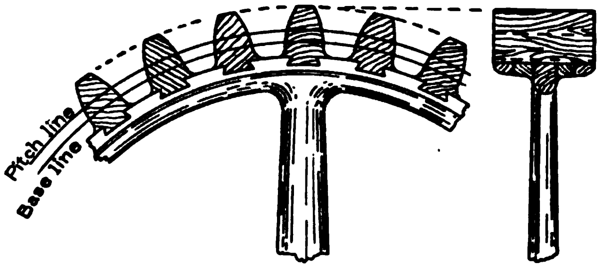


Fig. 236.

In the illustrations here given the single curve form of tooth is used.

In the construction of gear-wheel patterns, the methods employed in making and fastening the tooth, or the blocks out of which the teeth are to be formed, to the rim of the wheel, varies greatly. It was formerly the custom to dovetail the tooth into the rim of the wheel as shown in Fig. 236. This was the case especially when the teeth were large, as in 2 pitch or larger.

This is, however, an unnecessary expense and a waste of time, and in addition, the cutting of the dovetails and the driving home of the dovetailed tooth, often have the effect of distorting the rim to some extent. A better, or at least a more economical method is to fit the tooth blocks as shown in Fig. 237, which for strength and durability is found to be in no way inferior to dovetailing, and the saving of labor and time is very great.

In this method we have always the advantage of a smooth, clean fillet at the root of each tooth, and having the grain of the wood, not only for the fillets, but also on the whole depth circle, run in the same direction as the grain of the wood which forms the tooth. This means a smoother pattern, more easily moulded, and a better casting.

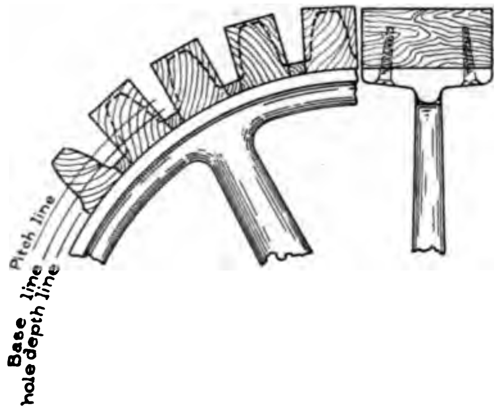


Fig. 237.

In the former method, Fig. 236, it is almost impossible to form a fillet on each side of the tooth, as it runs off to a thin feather edge which continually splinters and chips off; still further, the bottom of the tooth space, that is, the whole depth circle is the rim of the wheel, composed of layers of segments with changing grain which will not mould so smoothly as in the second method.

The blocks for the teeth should always be cut in strips two or three feet in length, in order to thoroughly season the wood, at least so far as it is possible to do so, while other parts of the wheel are being constructed.

Only straight-grained wood should be used for teeth. The segments for building up the rim should be cut out next, then the arms put together and shaped as required. It is a good plan to fasten the arms central to the face plate of the lathe, and to turn out a recess, say $\frac{1}{16}$ inch or $\frac{3}{32}$ inch deep to receive the hubs as shown in Fig. 238. This makes a stronger connection and does away with the trouble of fitting and connecting the hub, with the thin feather edge of the hub fillet, to the surface of the web of the arms. The same method is of great advantage when fitting the hubs of pulleys and other wheels. The arms must be put together, with inserted tongues in the joints, as illustrated and described in Fig. 169; and if they are to be worked to an elliptical section, it is easier to do this before fixing them in the wheel. At A, Fig. 238, the construction of the arms is shown, and at B the core prints, hubs and arms, with the manner of connecting these parts.

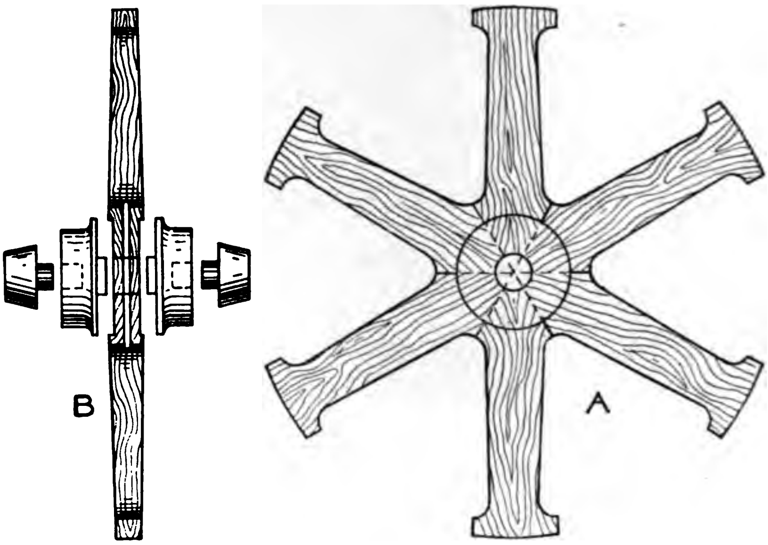
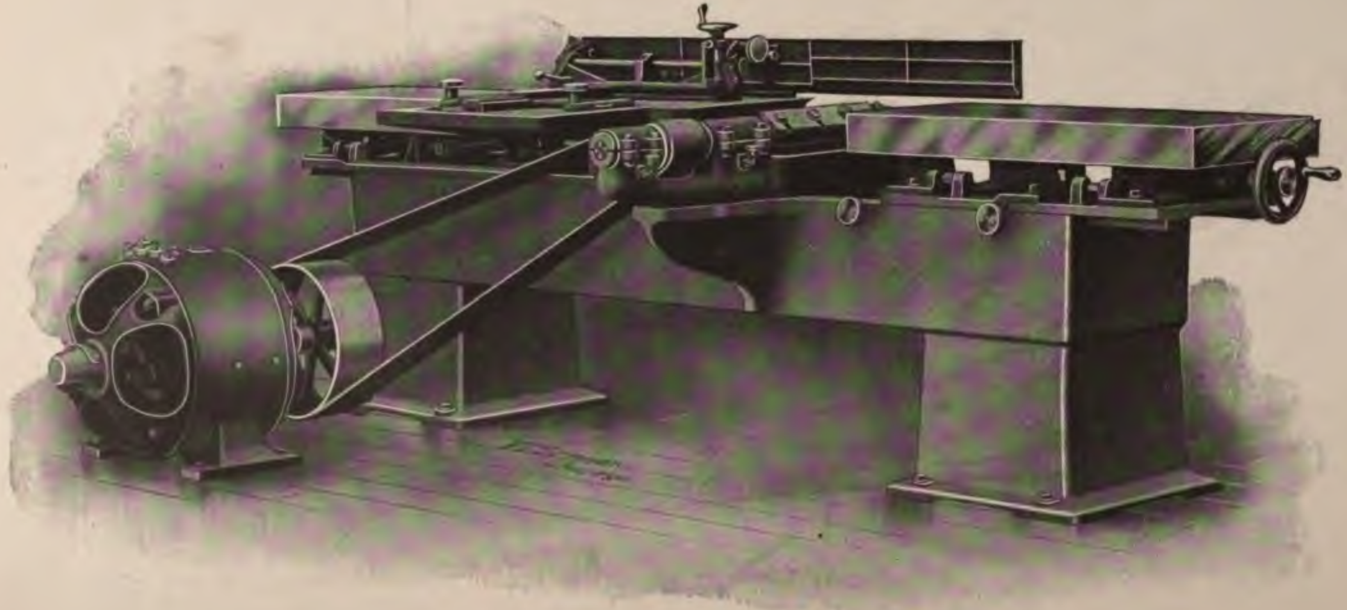


Fig. 238.

After building up enough courses of segments to equal half the width of the rim plus half the thickness of the arms, the inside only of this part of the rim is turned out to the required shape, including the central rib *a* Fig. 239, which must be of a thickness just equal to the thickness of the ends of the arms. The recesses to



HAND PLANER AND JOINTER.
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receive these ends are now cut into this half rim, and the arms fitted and glued in place but not so tightly as to strain the rim and cause it to spring after it is removed from the chuck. The remaining courses for the rim are now fitted and glued on, and the rim turned and finished to the required size and shape.

The face should be glue-sized to prepare it for the blocks which are to form the teeth of the gear.

After sizing and removing the raised grain of the wood, the periphery of the wheel must be spaced for the required number

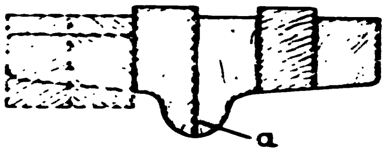


Fig. 239.

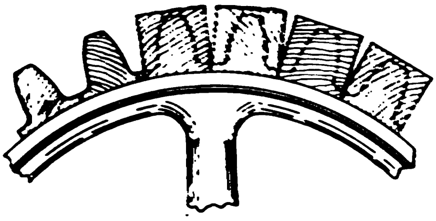


Fig. 241.

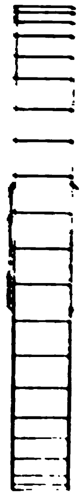
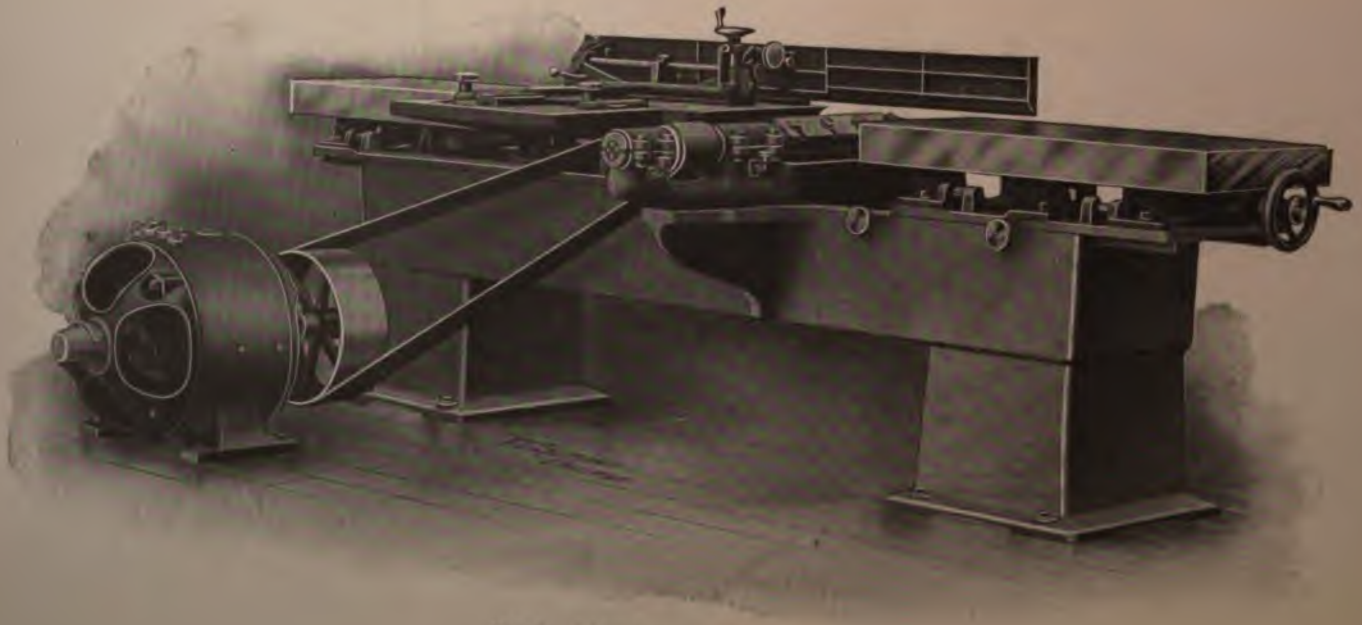


Fig. 240.

of teeth. With a try square and very sharp awl draw lines through the points obtained by the spacing as shown in Fig. 240. Should the teeth be of moderate size, say 3 pitch or less, the tooth blocks should be glued on so as to meet each other on the rim of the wheel as shown in Fig. 241.

Each block must be so fitted as to reach only from line to line, Fig. 240, care being taken to have each block parallel to, and coincide with its own line, *reaching exactly to the line*. When all the blocks are placed and glued, the wheel is returned to the lathe and the periphery turned off straight and to the required diameter for the addendum, or extreme ends of the teeth. The ends of the blocks are also turned even with the edge of the wheel rim,



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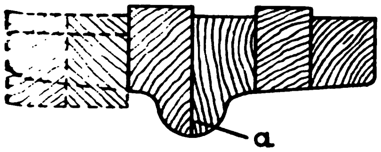


Fig. 239.

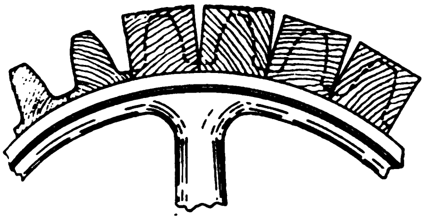
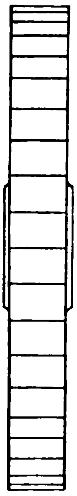


Fig. 241.



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For convenience in cutting and paring, a second series of lines should now be drawn across the face of each block connecting the extreme ends of the lines which describe the shape of the tooth on each end of the block. Should the wheel be small and within the capacity of the band saw, all superfluous wood may easily be removed from between the teeth.

If the band saw is sharp and evenly set, and the operator skillful, the teeth may be sawed so as to need but very slight correction with the paring chisel and gouge.

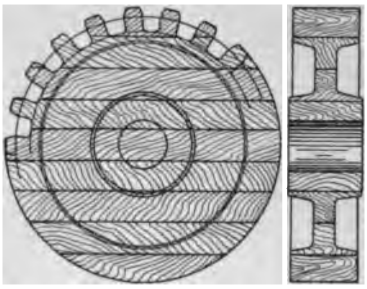


Fig. 243.

As the hubs usually project beyond the rim on each side of the wheel, they should be left loose and removed before placing the wheel on the saw table.

For large wheels and heavier teeth, each tooth block should be unscrewed and removed, one at a time, and planed to the lines marked on its ends and face, after which it is returned to its place before a second one is taken off. This is continued until all the teeth are shaped, when it will be necessary only to construct fillets at the base of the teeth, and also to work each space down to the *whole depth circle*, the circle having been drawn for this purpose, and also as a guide, for bringing all tooth spaces to the same depth.

Small gears, or pinions as they are called, are usually made with a solid web instead of arms, and are glued up in solid blocks of end wood, the grain of the entire block running parallel with the face of the teeth. Such an end wood pinion is shown in Fig. 243. It is turned and the gear laid out and cut in the same way as described for the larger wheels, except that the teeth are not glued on but cut out in the solid disc. In the construction shown in Fig. 241, the teeth, not being screwed on, must be nailed with brads, after being shaped and finished, from the face of each tooth into the rim.

Patterns for Bevel Gears are built up as illustrated at *a*, Fig. 244, the wooden face-plate, or chuck, being provided with ten or more radial blocks as shown and described in Fig. 168. The advantage of the blocks is that they keep the first layer of segments out from the face-plate and give easier access to the back edge or angle of the rim while being turned.

The segments are usually made to overlap as shown, which is not only a saving of wood but also saves the time which would be required to turn the angular rim from a square construction. When a sufficient number of courses have been built up, the face and two edges are turned to the required angles, as indicated by the dotted lines in *a*, Fig. 244. The rib *c* which will finally be a continuation of the arms, is also turned to shape and to the thickness of the ends of the arms. The rim will then present the appearance shown at *b*, Fig. 244, except the arms which are here shown in place.

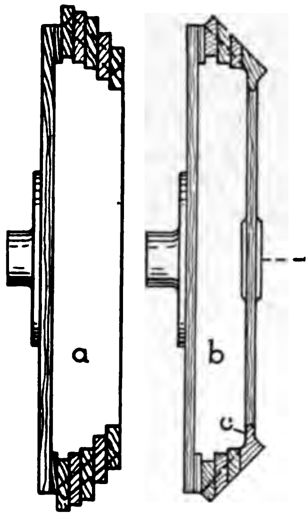


Fig. 244.

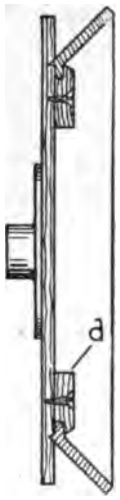


Fig. 245.

The rim is next cut from the blocks, and an angular groove turned in the face of the chuck which will fit and center the finished edge of the rim on the faceplate. In this position the inside of the rim is turned aud finished as shown in Fig. 245. The rim is retained on the chuck by four or six cleats, *d*, Fig. 245, the cleats fitting over the rib *c*, Fig. 244, and preventing the rim from moving and changing its position on the chuck.

It is not necessary here to describe the method used in finding the required angles for the face and edges of the rim, but as in the case of spur-gear teeth, the student should refer to Mechanical

Drawing. The arms, partly shown in Fig. 246, in place in Fig. 244, are next fitted and fastened to the rim. It is well to glue a small disc on each side of the web of the arms as shown in Fig. 246, which not only strengthens the arms, but serves as a fillet around the hub of the wheel.

The blocks for the teeth are next fitted in place, either as illustrated in Fig, 247, or in the form of alternate blocks and strips as was shown for the spur gear, Fig. 237. After all the blocks are in place, the wheel must be put in the lathe and turned to the sizes and angles required for laying out the teeth. A sharp line must be drawn on the face of the blocks, while in the lathe, to serve as a guide for the dividers while spacing the teeth.

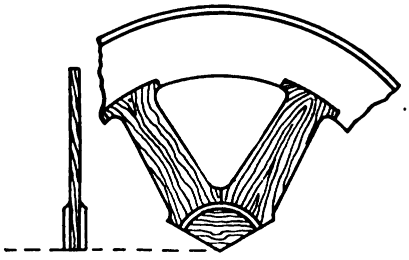


Fig. 246.

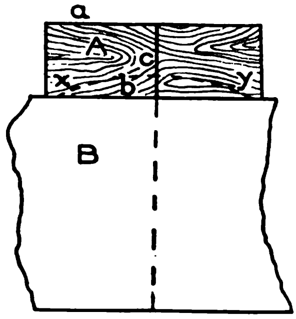


Fig. 248.

To obtain the center lines for the tooth faces after spacing on the blocks, it will be readily seen that the ordinary try square cannot be used as in the case of the spur gears. A temporary square must be made for this purpose as follows:

Take a piece of hard wood, about 6 inches long and 3½ inches wide and ½ inch in thickness. Dress the two edges perfectly parallel and from the upper edge *a*, Fig. 248, with a try square and a sharp pointed knife, draw the line *c*, equally distant from each end of A, and at right angles to the edge *a*. Lay the edge *b* of A, against another board B, of the same thickness, and continue the line *c* on this board as shown by the dotted line. With the dividers set to a radius equal to the longest radius of the outside ends of the tooth blocks, from the extended line *c* on the board B, describe the arc, *x y* on A. Cut the edge *b*, to this arc and see

, fits perfectly the outer rim of the tooth block. Next make . blade of hard wood and screw to the head A, using the st care to have one edge of the blade coincide exactly with e c. After screwing the blade to the head, its accuracy may ted by placing a try square against the edge *a*. The result as shown in Fig. 249, in which the edge *c* is radial to the *y*. This edge will describe the center lines of the teeth y as required.

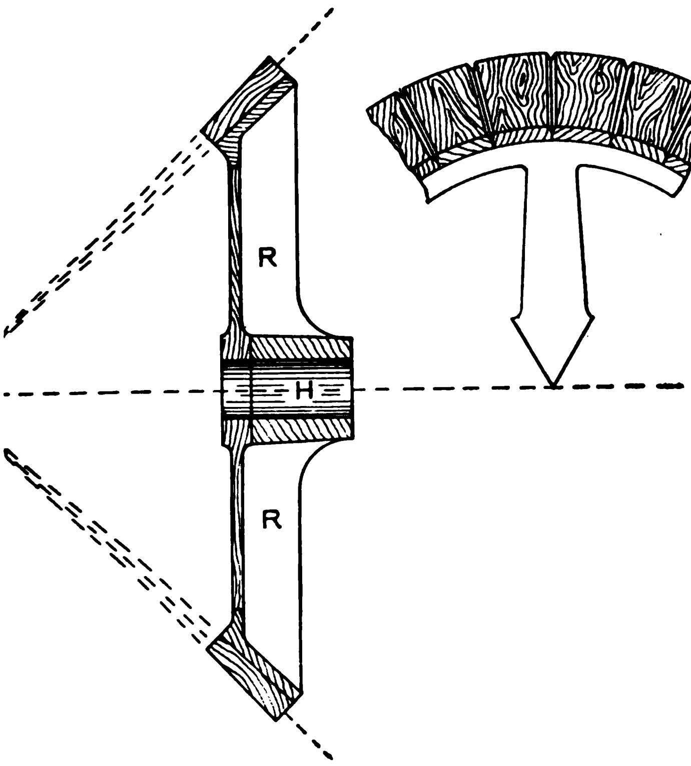


Fig. 247.

This temporary square can be used up to a certain limit, on ls of larger diameter than that to which it has been fitted, but ot be used for smaller wheels. For larger gears the position be as shown in Fig. 250, which will give the correct per- cular if the angles at *x* and *y* are carefully made. By using s way, only a few squares will be needed for a great number of wheels. In Fig. 247 the hub H and the ribs of the arms R R. are often made loose so as to lift with the cope, which is of great advantage in moulding. When the teeth are large, they must be screwed on from the inside of the rim. If small, they should be braded from the outside, or face of the tooth, into the rim *after* the teeth have been shaped and finished. Two templates will be necessary for laying out the ends of the teeth, the outer ends being larger than the inner. These templates are made as described for spur gears, and have the outer end bent to fit over the angles of the rim.

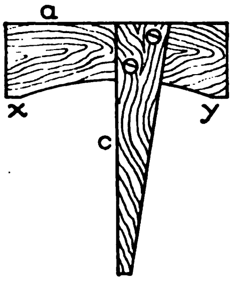


Fig. 249.

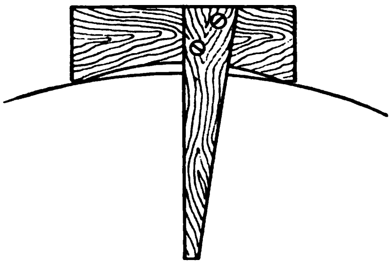


Fig. 250.

COLUMN PATTERNS

Cast-iron columns are often ornamented or fluted as shown in the half section of a fluted column in Fig. 251. In all such cases the body of the pattern is made octagonal as shown by the line A B C D E. The loose pieces forming the flutes are held to the main body by pins that stand at right angles to the line A E. After the sand has been rammed, the body included in the lines A B C D E is lifted out leaving the parts A *a b* B, B *b c* C, etc., imbedded in the sand. Then one after another these are lifted out.

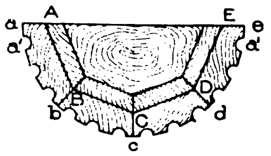


Fig. 251.

These fluted sections should never be so few in number that they cannot be lifted out without tearing the sand. Eight or twelve sections will be needed.

Other forms of ornamentation are put upon columns in a similar manner. Leaves or flowers are held by pins or in grooves in such a way that the main body of the pattern can be lifted out without disturbing them, and they are then withdrawn from the sand through the cavity left by the main pattern.

Cores for Columns. Cores for columns may be made in core boxes as in the case of those for pipe, but where the core is long and straight no core box is needed. The core is usually built of loam about an iron pipe as explained in Foundry Work.

Where the core is to follow the lines of the ornamental mouldings on the outside of the column, it may be provided with a special core box or better with a sweep as shown in Fig. 252. This sweep is used to shape the loam core that is to be built up on an iron pipe. Fig. 252 is the outline of the template that is to be used in sweeping the core for the interior of the columns shown in Fig. 253.

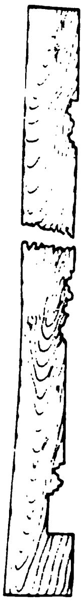


Fig. 252.

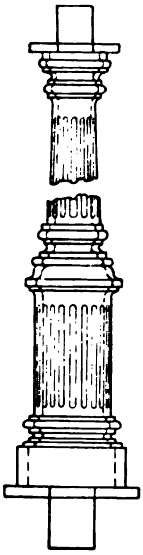


Fig. 253.

Follow Boards. All thin patterns that are likely to suffer distortion from the pressure of the sand while being rammed up, must be provided with accurately fitting follow boards. These follow boards may be made to fit on either one or other of the sides of the pattern.

When the outlines of the pattern are very irregular, the follow boards are often made of plaster or other composition, which, when dry, is used to support the pattern while the drag is being rammed.

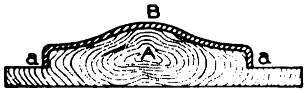
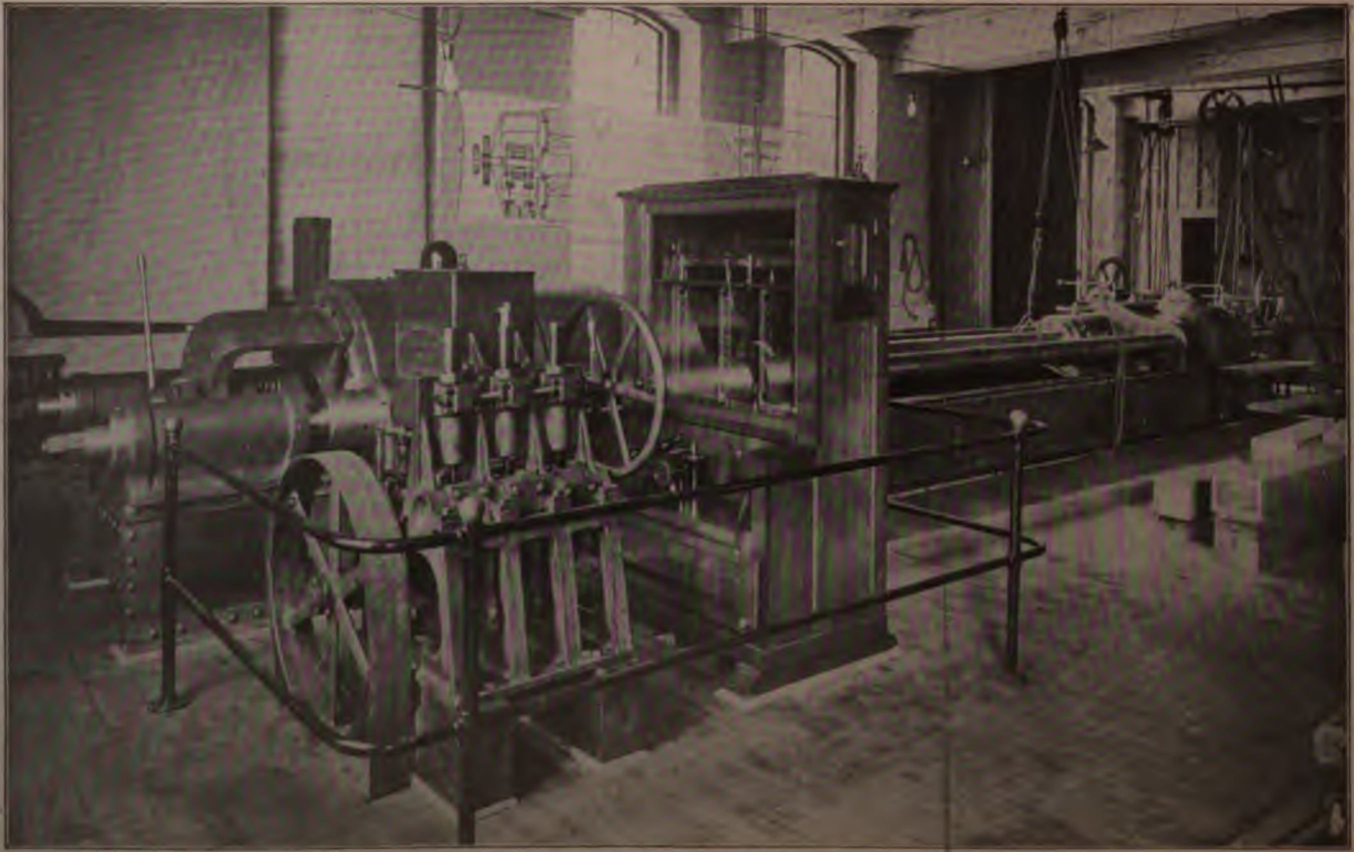


Fig. 254.

Fig. 254 represents a section of a railing cap. If the pattern B were to be set with the edges *a a* resting upon the moulding board and the sand of the drag rammed down upon its upper face, it would be sprung out of shape. To avoid this the follow board A is made to exactly fit the under side of the pattern. Then when the sand is rammed, the whole pattern is supported and there will be no distortion. When the cope is rammed the follow board is removed and the sand of the drag supports the pattern while the cope is being rammed.

PU



EMERY TESTING MACHINE.

Mechanical Engineering Department, Massachusetts Institute of Technology.

MACHINE DESIGN.

PART I.

Definition. Machine Design is the art of mechanical thought development, and specification.

It is an art, in that its routine processes can be analyzed and systematically applied. Proficiency in the art positively cannot be attained by any "short cut" method. There is nothing of a spectacular nature in the methods of Machine Design. Large results cannot be accomplished at a single bound, and success is possible only by a patient, step-by-step advance in accordance with well-established principles.

"Mechanical thought" means the thinking of things strictly from their mechanical side; a study of their mechanical theory, structure, production, and use; a consideration of their mechanical fitness as parts of a machine.

"Mechanical development" signifies the taking of an idea in the rough, in the crude form, for example, in which it comes from the inventor, working it out in detail, and refining and fixing it in shape by the designing process. Ideas in this way may become commercially practicable designs.

"Mechanical specification" implies the detailed description of designs, in such exact form that the shop workmen are enabled to construct completely and put in operation the machines represented in the designs.

The object of Machine Design is the creation of machinery for specific purposes. Every department of a manufacturing plant is a controlling factor in the design and production of the machines built there. A successful design cannot be out of harmony with the organized methods of production. Hence in the high development of the art of Machine Design is involved a knowledge of the operations in all the departments of a manufacturing plant. The student is therefore urged not only to familiarize himself with the direct production of machinery, but to study the relation thereto of the allied commercial departments

He should get into the spirit of business at the start, get into the shop atmosphere, execute his work just as though the resulting design were to be built and sold in competition. He should visit shops, work in them if possible, and observe details of design and methods of finishing machine parts. In this way he will begin to store up bits of information, practical and commercial, which will have valuable bearing on his engineering study.

The labor involved in the design of a complicated automatic machine is evidenced by the designer's wonderful familiarity with its every detail as he stands before the completed machine in operation and explains its movements to an observer. The intricate mass of levers, shafts, pulleys, gears, cams, clutches, etc., etc., packed into a small space, and confusing even to a mechanical mind, seems like a printed book to the designer of them.

This is so because it is a familiar journey for the designer's mind to run over a path which it has already traversed so many times that he can see every inch of it with his eyes shut. Every detail of that machine has been picked from a score or more of possible ideas. One by one, ideas have been worked out, laid aside, and others taken up. Little by little, the special fitness of certain devices has become established, but only by patient, careful consideration of others, which at first seemed equally good.

Every line, and corner, and surface of each piece, however small that piece may be, has been through the refining process of theoretical, practical, and commercial design. Every piece has been followed in the mind's eye of its designer from the crude material of which it is made, through the various processes of finishing, to its final location in the completed machine; thus its bodily existence there is but the realization of an old and familiar picture.

What wonder that the machine seems simple to the designer of it! As he looks back to the multitude of ideas invented, worked out, considered and discarded, the machine in its final form is but a trifle. It merely represents a survival of the fittest.

No successful machine, however simple, was ever designed that did not go through this slow process of evolution. No machine ever just simply happened by accident to do the work for which it is valued. No other principle upon which the successful design of machinery depends is so important as this careful, patient consideration of detail. A machine is seldom unsuccessful because some main point of construction is wrong. The principal features of a machine are usually the easiest to determine. It is a failure because some little detail was overlooked, or hastily considered, or allowed to be neglected, because of the irksome labor necessary to work it out properly.

There is no task so tedious, for example, as the devising of the method of lubricating the parts of a complicated machine. Yet there is no point of design so vital to its life and operation as an absolute assurance of an adequate supply of oil for the moving parts at all times and under all circumstances. Suitable means often cannot be found, after the parts are together, hence the machine goes into service on a risky basis, with the result, perhaps, of early failure, due to "running dry." Good designers will not permit a design to leave their hands which does not provide practically automatic oiling, or at least such means of lubrication that the operator can offer no excuse for neglecting to oil his machine. This is but a single illustration of many which might be presented to impress the definite and detail character necessary in work in Machine Design.

Relation. The relation which Machine Design should correctly bear to the problems that it seeks to solve, is twofold; and there are, likewise, two points of view corresponding to this twofold relation, from which a study of the subject should be traced. Neither of these can be discarded and an efficient mastery of the art attained. These points are—

I. Theory.
II. Production.

I. *Theory.* From this point of view, Machine Design is merely a skeleton or framework process, resulting in a representation of ideas of pure motion, fundamental shape, and ideal proportion. It implies a working knowledge of physical and mathematical laws. It is a strictly scientific solution of the problem at hand, and may be based purely on theory which has been reasoned out by calculation or deduced from experiment. This is the only sure foundation for intelligent design of any sort.

But it is not enough to view the subject from the standpoint of theory alone. If we stopped here we should have nothing but mechanisms, mere laboratory machines, simply structures of ingenuity and examples of fine mechanical skill. A machine may be correct in the theory of its motions; it may be correct in the theoretical proportions of its parts; it may even be correct in its operation for the time being; and yet its complication, its misdirected and wasteful effort, its lack of adjustment, its expensive and irregular construction, its lack of compactness, its difficulty of ready repair, its inability to hold its own in competition—any of these may throw the balance to the side of failure. Such a machine, commercially considered, is of little value. No shop will build it, no machinery house will sell it, nobody will buy it if it is put on the market.

Thus we see that, aside from the theoretical correctness of principle, the design of a machine must satisfy certain other exacting requirements of a distinctly business nature.

II. *Production.* From this point of view, Machine Design is the practical, marketable development of mechanical ideas. Viewed thus, the theoretical, skeleton design must be so clothed and shaped that its production may be cheap, involving simple and efficient processes of manufacture. It must be judged by the latest shop methods for exact and maximum output. It must possess all the good points of its competitor, and, withal, some novel and valuable ones of its own. In these days of keen competition it is only by carefully studied, well-directed effort toward rapid, efficient, and, therefore, cheap production that any machine can be brought to a commercial basis, no matter what its other merits may be. All this must be thought of and planned for in the design, and the final shapes arrived at are quite as much a result of this second point of view as of the first.

As a good illustration of this, may be cited the effect of the present somewhat remarkable development of the so-called "high speed" steels. The speeds and feeds possible with tools made of these steels are such that the driving power, gearing, and feed mechanism of the ordinary lathe are wholly inadequate to the demands made upon them when working the tool to its limit. This means that the basis of design as used for the ordinary tool steel will not do, if the machine is expected to stand up to the cuts possible with the new steels. Hence, while the old designs were right for the old standard, a new one has been set, and a thorough revision on a high-speed basis is imminent, else the market for them as machines of maximum output will be lost.

From these definitions it is evident that the designer must not only use all the theory at his command, but must continually inform himself on all processes and conditions of manufacture, and keep an eye on the tendency of the sales markets, both of raw material and the finished machinery product. This is what in the broadest sense is meant by the term "Mechanical Thought," thought which is directed and controlled, not only by theoretical principle but by closely observed practice. From the feeblest pretenders of design to those engineers who consummate the boldest feats and control the largest enterprises, the process which produces results is always the same. Although experience is necessary for the best mechanical judgment, yet the student must at least begin to cultivate good mechanical sense very early in his study of design.

Invention. Invention is closely related to Machine Design, but is not design itself. Whatever is invented has yet to be designed. An invention is of little value until it has been refined by the process of design.

Original design is of an inventive nature, but is not strictly invention. Invention is usually considered as the result of genius, and is announced in a flash of brilliancy. We see only the flash, but behind the flash is a long course of the most concentrated brain effort. Inventions are not spontaneous, are not thrown off like sparks from the blacksmith's anvil, but are the result of hard and applied thinking. This is worth noting carefully, for the same effort which produces original design may develop a valuable invention. But there is little possibility of inventing anything except through exhaustive analysis and a clear interpretation of such analysis.

Handbooks and Empirical Data. The subject matter in these is often contradictory in its nature, but valuable nevertheless. Empirical data are data for certain fixed conditions and are not general. Hence, when handbook data are applied to some specific case of design, while the information should be used in the freest manner, yet it must not be forgotten that the case at hand is probably different, in some degree, from that upon which the data were based, and unlike any other case which ever existed or will ever again exist. Therefore the data should be applied with the greatest discretion, and when so applied will contribute to the success of the design at least as a check, if not as a positive factor.

The student should at the outset purchase one good handbook, and acquire the habit of consulting it on all occasions, checking and comparing his own calculations and designs therefrom. Care must be taken not to become tied to a handbook to such an extent that one's own results are wholly subordinated to it. Independence in design must be cultivated, and the student should not sacrifice his calculated results until they can be shown to be false or based on false assumption. Originality and confidence in design will be the result if this course be honestly pursued.

Calculations, Notes, and Records. Accurate calculations are the basis of correct proportions of machine parts. There is a right way to make calculations and a wrong way, and the student will usually take the wrong way unless he is cautioned at the start.

The wrong way of making calculations is the loose and shiftless fashion of scratching upon a scrap of detached paper marks and figures, arranged in haphazard form, and disconnected and incomplete. These calculations are in a few moments' time totally meaningless, even to the author of them himself, and are so easily lost or mislaid that when wanted they usually cannot be found.

Engineering calculations should always be made systematically, neatly, and in perfectly legible form, in some permanently bound blank book, so that reference may always be had to them at any future time for the purpose of checking or reviewing. Put all the data down. Do not leave in doubt the exact conditions under which the calculations were made. Note the date of calculation.

If a mistake in figures is made, or a change is found necessary, never rub out the figures or tear out the leaf, or in any way obliterate the figures. Simply draw a bold cross through the wrong part and begin again. Often a calculation which is supposed to be wrong is later shown to be right, or the facts which caused the error may be needed for investigation and comparison. Time which is spent in making figures is always valuable time, time too precious to be thrown away by destroying the record.

The recording of calculations in a permanent form, as just described, is the general practice in all modern engineering offices. This plan has been established purely as a business policy. In case of error it locates responsibility and settles dispute. Consistent designing is made possible through the records of past designs. Proposals, estimates, and bids may often be made instantly, on the basis of what these record books show of sizes and weights. This bookkeeping of calculations is as important a factor of systematic engineering as bookkeeping of business accounts is of financial success.

The student should procure for this purpose a good blank book with a firm binding, size of page not smaller than 6 by 8 inches (perhaps 8 by 11 inches may be better), and every calculation, however small and apparently unimportant, should be made in it.

Sample pages of engineering calculations are reproduced in Figs. 3 to 9. Note the sketch showing the forces. Note the clear statement of data. Note the systematic writing of the equations, and the definite substitutions therein. Note the heavy double underscoring of the result, when obtained. There is nothing in the whole process of the calculation that cannot be reviewed at any moment by anybody, and in the briefest time.

The development of a personal note-book is of great value to the designer of machinery. The facts of observation and experience recorded in proper form, bearing the imprint of intimate personal contact with the points recorded, cannot be equalled in value by those of any hand or reference book made by another. There is always a flavor about a personal note-book, a sort of guarantee, which makes the use of it by its author definite and sure.

The habit of taking and recording notes, or even knowing what notes to take, is an art in itself, and the student should begin early to make his note-book. Aside from the value of the notes themselves as a part of his personal equipment, the facility with which his eye will be trained to see and record mechanical things will be of great value in all of his study and work. How many men go through a shop and really see nothing of the operations going on therein, or, seeing them, remember nothing! An engineer, trained in this respect, will to a surprising degree be able to retain and sketch little details which fall under his eye for a brief moment only, while he is passing through a crowded shop.

Some draftsmen have the habit of copying all the standard tables of the various offices in which they work. While these are of some value in a few cases, yet this is not what is meant by a good note-book in the best sense. Ideas make a good note-book, not a mere tabulation of figures. If the basis upon which standards are founded can be transferred to permanent personal record, or novel methods of calculation, or simple features of construction, or data of mechanical tests, or efficient arrangement of machinery—if *these* can be preserved for reference, the note-book will be of greatest value.

Whatever is noted down, make clear and intelligible, illustrating by a sketch if possible. Make the note so clear that reference to it after a long space of years would bring the whole subject before the mind in an instant. If this is not done the author of the note himself will not have patience to dig out the meaning when it is needed; and the note will be of no value.

METHOD OF DESIGN.

The fundamental lines of thought and action which every designer follows in the solution of any problem in any class of work whatsoever, are four in number. The expert may carry all these in mind at the same time, without definite separation into a a step-by-step process; but the student must master them in their proper sequence, and thoroughly understand their application. In these four are concentrated the entire art of Machine Design. When they have become so familiar as to be instinctively applied on any and all occasions, good design is the result. The only other quality which will facilitate still further the design of good machinery is experience; and that cannot be taught, it must be acquired by actual work.

1. Analysis of Conditions and Forces. First, take a good square look at the problem to be solved. Study it from all sides, view it in all lights, note the worst conditions which can possibly exist, note the average conditions of service, note any special or irregular service likely to be called for.

With these conditions well in mind, make a careful analysis of all the forces, maximum as well as average, which may be brought into play. Make a rough sketch of the piece under consideration, and put in these forces. Be sure that these forces are at least approximately right. Go over the analysis carefully again and again. Remember that time saved at the beginning by hasty and poor analysis will actually be time lost at the end; and if the machine actually fails from this reason, heavy financial loss in material and labor will occur. Any haste toward completion of the structure beyond the roughest outline, without this careful study of forces, is a blind leap in the dark, entirely unscientific, and almost certain to result in ultimate failure.

On the other hand this principle may be carried too far. In trying to make the analysis thorough and the forces accurate, it is quite possible to consume more than a reasonable amount of time. Again, it is not always easy, and frequently impossible, to determine exactly the forces acting on a given piece. But their *nature*, whether sudden or slowly applied, rapid in action or only occurring at intervals, and their *approximate* direction and magnitude at least, are always capable of analysis. There are few, if any, cases where close assumptions cannot be made on the above basis and the design proceeded with accordingly. Hence the danger of too great refinement of analysis is simply to be avoided by the designer's plain business sense.

The first tendency of the student is to pass over the study of the forces as dull and dry, and attempt the design at once. He soon finds himself facing problems of which he sees no possible solution, and he bases his design on pure guess-work. This is the only solution possible from such a point of view, and is really no solution at all. A guess which has some rational backing is often successful; but in that case some analysis is required, and it is not a pure guess, but falls under the very principle we are considering.

There is no short cut to the design of machine parts which avoids this full understanding of the forces that they must sustain. The size of a belt depends upon the maximum pull upon it, and the designing of belts is nothing but providing sufficient cross-section of leather to prevent the belt tearing under the pull. Again, if pulley arms are not to break, or shafts twist off, or bolts be torn apart, or the teeth of gears fail, or keys and pins shear off, we must first, of course, find out what forces exist which are likely to produce stress that may lead to such breakage. We should not guess at the sizes, and then run the machine to see if breakage results, and then guess again. Machines are sometimes built in this way, but it is an unreasonable and uncertain method. We must use every effort to foresee the stress which a piece is liable to receive, before we decide its size. We must know all the forces approximately, if not positively. The analysis must be thorough enough to permit of reasonable assumption, if not positive assertion. It is manifestly impossible to solve any problem until we know exactly what the problem is; and a full analysis *is* the statement of the problem.

2. **Theoretical Design.** After we know by careful analysis what stress the machine part has to sustain, the next step is so to design it that it will theoretically resist the applied forces with the least expenditure of material.

We often see machinery with the metal of which it is made distributed in the worst possible manner. In places where the stress is heavy and a rigid member is needed, we find a weak, springy part; while in other parts, where there are no forces to be resisted, or vibration to be absorbed, there seems to be a waste of good material. Whether in such case the analysis of the forces was poor, or perhaps not made at all, or whether a knowledge of how to design so as to resist the given forces was wholly absent, cannot be told. At any rate, lack of either or both is clearly shown in the result.

Any member of a machine may vary in form from a solid block or chunk of material to an open ribbed structure. The solid chunk fills the requirement as far as strength is concerned, unless it is so heavy as to fail from its own weight. But such construction is poor design, except in cases where the concentration of heavy mass is necessary to absorb repeated blows like those of a hammer. The possibility of these blows should, however, have been determined in the analysis; and the solid, anvil construction then becomes theoretical design for that analysis.

For steadily applied loads an open, ribbed, or hollow box structure can be made which will distribute the metal where it is theoretically needed, and each fiber will then sustain its proper share of the load. In this way weight, cost, and appearance are heeded; and the service of the piece is as good as, and probably better than, it would be with the clumsy, solid form.

There is no such thing as putting too much theory into the design of machinery. The strongest trait which an engineer can have is absolute faith in his analysis and calculations, and their reproduction in his theoretical design. Theoretical design is an indication of scientific advance in the art, and some of the greatest steps of progress which have been made in recent years have been accomplished through a purely theoretical study of machine structure.

It will never do, however, to be satisfied with theoretical design when it is not in accord with modern commercial and manufacturing considerations. Hence the next step after the determination of the theoretical design is the study of it from the producing standpoint.

3. Practical Modification. All theoretical design viewed from the business standpoint is worthless, unless it has been subjected to the test of cheap and efficient production. Each machine detail, though correct in theory, may yet be improperly shaped and unfit for the part it is to play in the general scheme of manufacture.

The conditions here involved are changeable. What is good design in this decade may be bad in the next. In this light the designer must be a close student of the signs of the times; he must follow the march of progress, closely applying existing resources, conditions, and facilities, otherwise he cannot produce up-to-date designs. The introduction of new raw materials, the cheapening of production of others, the changing of shop methods, the use of special machinery, the opening of new markets, the development of new motive agents, — all these and many others are constantly demanding some modification in design to meet competition.

Illustrative of this, note the change which has been wrought by the development of electric power, the rise and decline of the bicycle business, the present manufacture of automobiles, the last named especially with reference to the development of the small motive unit, the gasolene engine, the steam engine, etc. The design of much machinery has been materially changed to meet the exacting demands of these new enterprises.

Practical modifications of design necessary to meet the limitations of construction in the pattern shop, foundry, and machine shop are of daily application in the designer's work. He must keep in his mind's eye at all times the workmen and the processes they use to create his designs in metal in the shop.

"How can this be made?" "Can it be made at all?" "Can it be made cheaply?" "Will it be simple in operation after it is made?" "Can it be readily removed for repair?" "Can it be lubricated?" "How can it be put in place?" "How can it be gotten out?" "Will it be made in small quantities or large?" "Will it sell as a special or standard machine?" etc., etc.

The consideration of such questions as these is a practical necessity as a business matter. No other feature affects the design of machinery more, perhaps; for designs which cannot be built as business propositions are no designs at all.

The student, it is true, may not have the extended shop knowledge which is essential to this; but he can do much for himself by visiting shops whenever possible, getting hold of shop ways of doing things, and invariably treating his work as a business matter. Though a man may not be a pattern maker, molder, blacksmith, or machinist, yet he can soon gain ideas of the processes in each of these branches which will be of immense advantage to him in his designing work.

4. **Delineation and Specification.** This means the clear and concise representation of the design by mechanical drawings.

This is as much a part of the routine method of Machine Design as the other three points which have been discussed. The mere act of putting the results of mechanical thinking on paper is one of the greatest helps to force thinking machinery to systematic and definite action. A designer never thinks very long without drawing something, and the student must bring himself to feel that a drawing in its first sense is a means of helping his own thought, and must freely use it as such.

In its second and final sense, the drawing is an order and specification sheet from the designer to the workman. Design which stops short of exact, finished delineation in the form of working shop drawings is only half done. In fact the possibility of a piece being thus exactly drawn is often the crucial test of its feasibility as a part of a machine. It is easy to make general outlines, but it is not so easy to get down to finished detail. It is safe to say that there is no one thing productive of more trouble, delay and embarrassment, and waste of time and money in the shop, when there need be none from this cause, than a poor detail drawing. The efficiency of the process of design is not fully realized, and failures are often recorded where there should be success, merely because the indefiniteness permitted by the designer in the drawings naturally transmitted itself to the workman, and he in turn produced a part indefinite in form and operation.

The actual process of drawing in the development of a design may be outlined as follows :

Rough sketches merely representing ideas, not drawn to scale, are first made. These are of use only so far as the choice of mechanical ideas is concerned, and to carry preliminary dimensions.

Following these sketches, comes a layout to scale, of the favored sketch, a working out of the relative sizes and location of the parts. This drawing may be of a sketchy nature, carrying a principal dimension here and there to fix and control the detailed design. In this drawing the design is developed and general detail worked out. The minute detail of the individual parts is, however, left to the subsequent working drawing.

This layout drawing may now be turned over to an expert draftsman or detail designer, who picks out each part, makes an exact drawing of it, studying every little detail of its shape, and finally adds complete dimensions and specifications so that the workman is positively informed as to every point of its construction.

General drawings and cross sections constitute the last step in the process of complete delineation. These show the parts assembled in the complete machine. They also serve a valuable purpose to the draftsman in checking up the dimensions of the detail drawings. Errors which have escaped previous notice are often discovered in this way. The layout, mentioned above, is sometimes finished up into a general drawing: but it is safer to make an entirely new drawing, as changes in detail are often necessary after the layout is made.

The four fundamental lines of thought and action noted above may be summarized thus—"**analyze and theorize, modify and delineate.**" This is a maxim easy to remember, applicable to every problem in Machine Design, and always provides the answer to the question "What shall I do, how shall I proceed?" by pointing out the proper sequence in the course to be followed.

CONSTRUCTIVE MECHANICS.

Mechanics is a constructive science, its principles lying at the root of the design and operation of all machinery. It is usually taught, however, as an advanced mathematical subject; and the student gets his original conceptions of forces, moments, and beams in the abstract, before he realizes the constructive value of such conceptions. By "Constructive Mechanics" is meant the study of a machine purely from its constructive side, the viewing of the parts with respect to their "mechanics," and satisfying the requirements of the same in form and arrangement.

The student may cultivate this habit of clear, mechanical perception by constantly noting the "mechanics" of the simple structures which he sees in his daily routine of work. Aside from machinery, in which the "mechanics" is often obscure, the world is full of simple examples of natural strength and symmetry, explainable by application of the principles of pure "mechanics."

Posts and pillars are largest at their bases; overhanging brackets or arms are spread out at the fastening to the wall; heavy swinging gates are counter-balanced by a ponderous weight; the old-fashioned well sweep carries its tray of stones at the end, adjusting the balance to a nicety; these are examples of things depending for their form and operation upon the principles of "mechanics." The building of them involved "constructive mechanics," and yet their constructor perhaps never heard of the science, using merely his natural sense of mechanical fitness. Such simple reasoning is, however, Constructive Mechanics.

Forces, Moments, and Beams. Machines are nothing but a collection of (1) parts taking direct stress, or (2) parts acting as loaded beams. Forces acting *without* leverage produce direct stress on the sustaining part. Forces acting *with* leverage produce a moment; the sustaining member is a beam, and the stress therein depends on the theory of beams, as explained in "Mechanics."

An example of the first is the load on a rope, the force acting without leverage, and the rope therefore having a direct stress put upon it.

An example of the second is a push of the hand on the crank of a grindstone. A moment is produced about the hub of the crank; the arm of the crank is a beam, and the stress at any point of it may be found by the method of theory of beams.

Tension, Compression, and Torsion. The stress induced in the sustaining part, whether tensile, compressive, or torsional, is caused by the application of forces, either acting directly without leverage, or with leverage in the production of moments.

The forces applied from external sources are at constant war with the resisting forces due to the strength of the fibres of the material composing the machine members. The moments of the *external* forces are constantly exerted against and balanced by the moments of the *internal* resistance of the material. Hence, design, from a strength standpoint, is merely a balancing of internal strength against external force. In other words, we may in all cases write a sign of equality, place the applied effort on one side, the effective resistance on the other, and we shall have an equation, which, if capable of solution, will give the proper proportions of the parts considered.

External Force = Internal Resistance.

External Moment = Internal Moment of Resistance.

Expressed in terms of the "Mechanics:"

$$P = AS \qquad (1)$$

$$B \text{ or } T = \frac{SI}{c} \qquad (2)$$

In these formulas, which are perfectly general,

P=direct load in pounds.

A=area of effective material, in square inches.

S=working fibre stress of the material (tensile, compressive, or shearing), in pounds per square inch.

B or T=external moment (bending or torsional), in inch-pounds.

I=moment of inertia (direct or polar), of the resisting section.

c=distance of the most remote fibre of the resisting section from the neutral axis.

P may produce direct tensile, compressive, or shearing stress.

B may produce tensile or compressive stress, and requires use of direct moment of inertia in either case.

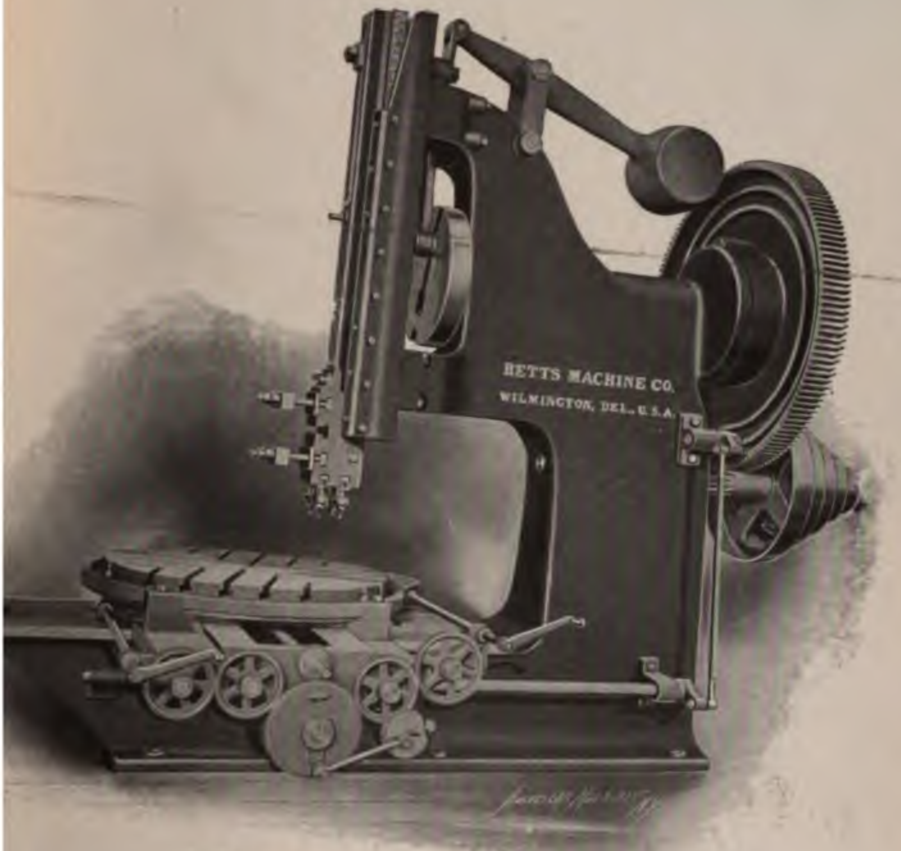
T produces shearing stress, and requires use of polar moment of inertia.

The origin of formula (1) is obvious, the assumption being that the fibre stress is equally distributed to every particle in the area "A."

The development of formula (2) is given in any text-book in Mechanics. It requires the aid of the Calculus, however. Any good handbook gives values for both the direct moment of inertia and the polar moment of inertia for quite a large variety of sections, so that further reference is an easy matter for the student. These values are also obtained through the methods of the Calculus.

The reason for introducing these formulas at this time is to call the attention of the student especially to the fact of their universal and fundamental use in all problems concerning the strength of machine parts. Nearly every computation may be reduced to or expanded from these two simple equations. Many complex combinations occur, of course, which will not permit simple and direct application of these formulas, but the student will do well to place himself in perfect command of these two. Assuming that he is able to analyze forces, and compute the simple moment at the point where he wishes to find the strength of section, the rest is the mere insertion of the assumed working fibre stress of the material in the formula (2) above, and solution for the quantity desired.

When the case is one of combined stress, the relation becomes more complicated and difficult of analysis and solution. The most common case is where bending is combined with torsion, as in the case of a shaft transmitting power, and at the same time loaded transversely between bearings. In fact there are very few cases of shafts in machines, which, at some part of their length, do not have this combined stress. In this case the method of procedure is to find the simple bending moment and the simple torsional moment separately, in the ordinary way. Then the theory of elasticity furnishes us with a formula for an equivalent bending or an equivalent torsional moment which is supposed to produce the same effect upon the fibres of the material as the combined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tion of the two simple moments acting together. In other ords, the separate moments combined in action, being impossible solution in that form, are reduced to an equivalent simple oment and the solution then becomes the same as for the prev-ous case.

These equivalent equations are given below, the subscript "e" eing added to express separation from the simple moment:

$$B_e=\frac{B}{2}+\tfrac{1}{2}\sqrt{B^2+T^2} \qquad (3)$$

$$T_e=B+\sqrt{B^2+T^2} \qquad (4)$$

B_e and T_e, found from these equations, are the external moments, and are to be equated to the internal moments of resistance of the section precisely as if they were simple bending or torsional moments. Either may be used. For shafts (4) is generally used, being the simpler of the two in form.

FRICTION AND LUBRICATION.

The parts of a machine which have no relative motion with regard to each other are not dependent upon lubrication of their surfaces for the proper performance of their functions. In cases where relative motion does occur, as between a planer bed and its ways, a shaft and its bearing, or a driving screw and its nut, friction, and consequent resistance to motion, will inevitably occur. Heat will be generated, and cutting or scoring of the surfaces will take place if the surfaces are allowed to run together dry.

This difficulty, which exists with all materials, cannot be overcome, for it is a result of roughness of surface characteristic of the material even when highly finished. The problem of the designer, then, is to take conditions as he finds them, and, as he cannot change the physical characteristics of materials, so choose those which are to rub together in the operation of the machine that friction will be reduced to the lowest possible limit. Now it fortunately happens that there are certain agents like oil and graphite, which seem to fill up the hollows in the surface of a solid material, and which themselves have very little friction on other substances. Hence, if a machine permits by its design an automatic supply of these lubricating agents to all surfaces [illegible] motion between them, friction may be reduced to the lowest limit.

If this full supply of lubricant be secured, and the parts still heat and cut, then the fault may be traced to other causes, such as springy surfaces, localization of pressure, or insufficient radiating surface to carry away the heat of friction as fast as it is generated.

Lubricating agents are of a nature running from the solid graphite form to a thick grease, then to a heavy dark oil, and finally to a thin, fluid oil flowing as freely as water. The solid and heavy lubricants are applicable to heavily loaded places where the pressure would squeeze out the lighter oils. Grease, forced between the surfaces by compression grease cups, is an admirable lubricator for heavy machinery under severe service. High-speed and accurate machinery, lightly loaded, requires a thin oil, as the fits would not allow room for the heavier lubricants to find their way to the desired spot. The ideal condition in any case is to have a film of lubricant always between the surfaces in contact, and it is this condition at which the designer is always aiming in his lubricating devices.

Oil ways and channels should be direct, ample in size, readily accessible for cleaning, and distributing the oil by natural flow over the full extent of the surface. Hidden and remote bearings must be reached by pipes, the mouths of which should be clearly indicated and accessible to the operator of the machine. Such pipes must be straight, if possible, and readily cleaned.

There is one practical principle affecting the design of methods of lubrication of a machine which should be borne in mind. This is, "Neglect and carelessness by the operator *must* be provided for." It is of no use to say that the ruination of a surface or hidden bearing is due to neglect by the operator, if the means for such lubrication are not perfectly obvious. This is "locking the door after the horse is stolen." The designer has not done his duty until he has made the scheme of lubrication so plain that every part *must* receive its proper supply of oil, except by gross and willful negligence, for which there can be no possible just excuse.

WORKING STRESSES AND STRAINS.

Some persons object to the use of these terms, as one is frequently used for the other, and misunderstanding results. This is doubtless true; but the student may as well learn the true relation of the terms once for all, because he will frequently run across them in his reading and reference work, and should interpret them rightly. The strict relation of the two is as follows:

Stress is the internal force in a piece resisting the external force applied to it. A weight of ten pounds hanging on a rope produces a *stress* of ten pounds in the rope.

Strain is the change of shape, or deformation, in a piece resisting an external force applied to it. If the above weight of ten pounds stretches the rope $\frac{1}{4}$ inch, the *strain* is $\frac{1}{4}$ inch.

Unit stress is stress per unit area, e. g., per square inch.

Unit strain is strain per unit length, e. g., per inch length.

In the above case, if the rope were $\frac{1}{2}$ square inch in area and 30 inches long, the unit stress, or intensity of stress, is $10 \div \frac{1}{2} = 20$ pounds per square inch; the unit strain is $\frac{1}{4} \div 30 = \frac{1}{120}$ inch per inch.

When stress is induced in a piece, the strain is practically proportional to the stress for all values of the stress below the elastic limit of the material; and when the external load is removed the strain will entirely disappear, or the recovering power of the material will restore the piece to the original length.

Illustrating by the case above, on the supposition that the elastic limit has not been reached by the stress of 20 pounds per square inch, if the load of 10 pounds were taken off, the $\frac{1}{4}$-inch strain would disappear and the rope return to its original length; if the load were changed to $\frac{1}{2}$ of 10 pounds, or 5 pounds, the strain would be $\frac{1}{2}$ of $\frac{1}{4}$ inch, or $\frac{1}{8}$ inch.

Now it is found that if we wish a piece to last in service for a long time without danger of breakage, we must not permit it to be stressed anywhere near the elastic limit value. If we do, although it will probably not break at once, it is in a dangerous condition, and not well suited to its requirements as a machine member. The technical name for this weakening effect is "fatigue." It is further found that the fatigue due to this repeated stress is reached at a lower limit when the stress is alternating in character than when it is not. In other words, if we first pull on a piece and then push on it, we shall first have the piece in tension and then in compression; this alternation of stress repeated to near the elastic limit of the material will fatigue it, or wear out the fibres, and it will finally fail. If, however, we first pull on the piece with the same force as before, and then let go, we shall first have the piece in tension and then entirely relieved; such repetition of stress will finally "fatigue" the material, but not so quickly as in the first case. Experiments indicate that it may take twice as many applications in the latter case as in the former.

The working stress of materials permissible in machines is based on the above facts. The breaking strength divided by a liberal factor of safety will not necessarily give a desirable working stress. The question to be answered is, "Will the assumed working fibre stress permit an indefinite number of applications of the load without fatiguing the material?"

Hence we see that the same material may be safely used under different assumptions of working stress. For example, a rotating shaft, heavily loaded between bearings, acts as a beam which in each revolution is having its particles subjected, first to a maximum tensile stress, and then to a maximum compressive stress. This is obviously a very different stress from that which the same piece would receive if it were a pin in a bridge truss. In the former we have a case where the stress on each particle reverses at each revolution, while in the latter we have merely the same stress recurring at intervals, but never becoming of the opposite character. For ordinary steel, a value of 8,000 would be reasonable in the former case, while in the latter it may be much higher with safety, perhaps nearly double.

From the facts stated above, it is evident that exact values for working fibre stress cannot be assumed with certainty and applied broadly in all cases. If the elastic limit of the material is definitely known we can base our working value quite surely on that.

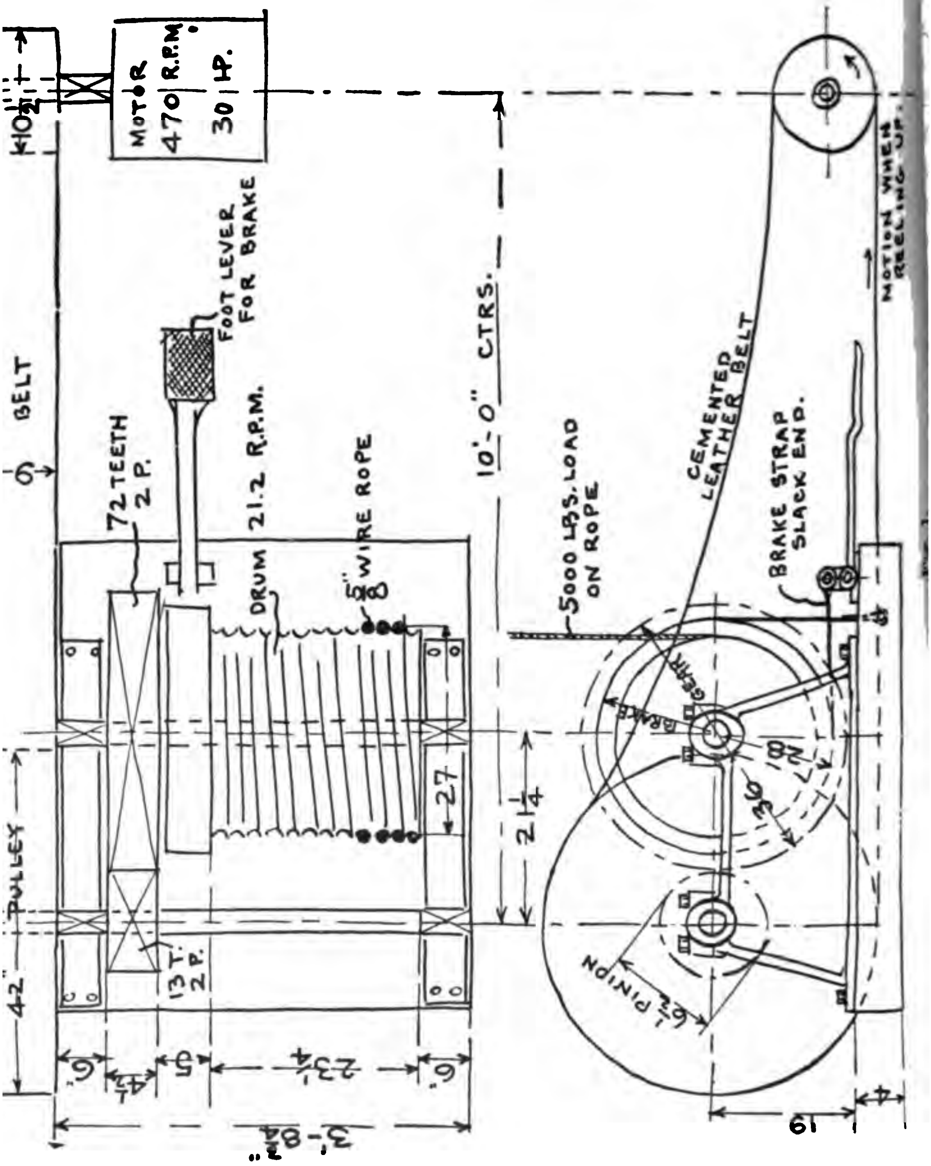
With but a general knowledge of the elastic limit, ordinary steel is good for from 12,000 to 15,000 pounds per square inch non-reversing stress, and 8,000 to 10,000 reversing stress. Cast iron is such an uncertain metal on account of its variable structure that stresses are always kept low, say from 3,000 to 4,000 for non-reversing stress, and 1,500 to 2,500 for reversing stress.

With these values as a guide, and the special conditions controlling each case carefully studied, reasonable limits may be assigned for working stress, not only of steels, various grades of cast iron, and mixtures of the same, but of other alloys, brass, bronze, etc. Gun metal, semi-steel, and bronze are intermediate in strength between cast iron and steel. Data on the strength of materials are available in any of the handbooks, and should be consulted freely by the student. They will be found somewhat conflicting, but will assist the judgment in coming to a conclusion.

Application to Practical Case. In actual practice the only information which the designer has, upon which to base his design, is the object to be accomplished. He must choose or originate suitable devices, develop the arrangement of the parts, make his own assumptions regarding the operation of the machine, then *Analyze and Theorize, Modify and Delineate* each detail as he meets it.

This, it will be found, is a very different matter from taking some familiar piece of machinery, such as a pulley, or a shaft, or a gear, as an isolated case, the load being definitely given, and proceeding with the design. This is easily done, but is only half the problem, for machine parts, such as pulleys, gears, and shafts, do not confront the designer tagged or labeled with the conditions they are to meet. He is to provide parts to meet the specific conditions, and it is as much a part of his designing method to know how to attack the design of a machine as it is to know how to design the parts in detail after the attack has reduced the members to definitely loaded structures. The whole process must be gone through, the preliminary sketches, calculations, and layout, all of which precede the detail design and working drawings; and no step of the process can be omitted.

It is for this reason that the present case used for illustration is carried out quite thoroughly. The student should make himself familiar with every step of the designing method as applied to this simple case of design. More complex problems, handled in the same way, will simplify themselves; and when the point is reached where confidence exists to take hold of the design of any machine, however unfamiliar its object may be, or however involved its probable detail appears, the student has become the true designer. It is the knowing how to attack a problem, to start definite work on it, to go ahead boldly, confident that the method applied will produce results, that gives command of the design of machinery and wins engineering success.



The special case which has been chosen to illustrate the application of the principles stated in the foregoing pages is ideal, in that it does not represent any actual machine at present in operation. Probably builders of hoisting machinery have devices which would improve the machine as shown. In detail, as well as arrangement, they could doubtless make criticism as manufacturers. The arrangement as shown is merely intended to bring out in simplest form the common elements of transmission machinery as parts of some definite machine, instead of as isolated details. The design is one entirely possible, practical, and mechanical, but special attention has been paid to simplicity in order to enable the student to follow the method closely, for the *method* is the chief thing for him to acquire.

The student is expected to refer constantly to Part II for a more formal and general discussion of the simple machine elements involved in the case considered. Part II is intended to be a simplified and condensed reference book, carried out in accordance with the method of machine design as specified in Part I. The student should not wait until he has completed the study of this part before taking up Part II, for the latter is intended for use with the former in the solution of the problems.

In the case of power transmission about to be studied, the running, conversational method employed assumes that the student is in possession of the matter in Part II on the subject considered. Thus, in the design of the pulley, reference to the subject of "Pulleys" in Part II is necessary to follow the train of calculation; in designing the gear, consult "Gears;" in calculating size of shafts, see "Shafts," etc., etc.

Problem. A machine is to be designed to be set on the floor of a building to drive a wire rope falling from the overhead sheaves of an elevator or hoist. Without regard to details of this overhead arrangement, for its design would be a separate problem, suppose that the data for the rope are as follows:

Load on rope	5,000 pounds.
Speed of rope	150 feet per minute.
Length of rope to be reeled in	200 feet.

We shall further assume that the driving power is to be an electric motor belted to the machine, that the required speed reduction can be satisfactorily obtained by a single pair of pulleys and one pair of gears, and that a plain band brake is to be applied to the drum.

With this data we shall proceed to work out the detail design of the machine.

Preliminary Sketch. The first thing to do is to sketch roughly the proposed arrangement of the machine.

This might appear like Fig. 1 except that it would have no dimensions in addition to the data given above. If the scheme seems suitable, the next step is to make such preliminary calculations as will give further data, exact or closely approximate sizes, to be put at once on the sketch, to outline the future design.

Rope and Drum. Referring to tables of strength of wire rope (Kent's Pocket Book gives the manufacturers' list), we find that a $\frac{5}{8}$-inch cast-steel rope will carry 5,000 pounds safely, and that the proper size of drum to avoid excessive bending of the rope around it is 27 inches diameter. Allowing $\frac{1}{8}$ inch between the coils as the rope winds on the drum, the pitch of coil will be $\frac{3}{4}$ inch as shown in sketch, Fig. 2. The length of one complete coil is, practically, $\frac{27 \times 3.1416}{12}$ $=7.07$ feet. To provide for 200 feet will require $\frac{200}{7.07}=28+$coils. To be safe, let us provide for 30 coils, for which a length of drum $(30 \times \frac{3}{4}) + \frac{3}{4} = 23\frac{1}{4}$ inches is required.

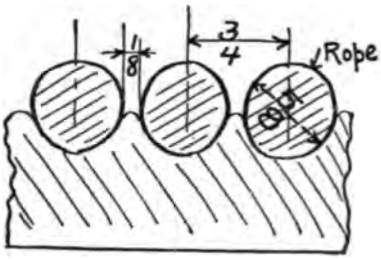


Fig. 2.

The space for brake strap may be assumed at 5 inches, and the thickness to provide necessary strength determined later in the design. The frictional surface of the strap may be of basswood blocks, say $1\frac{1}{4}$ inches thick, screwed to the metal band. The diameter of brake surface may be 28 inches.

Driving Gears. The size of drum gear evidently depends upon the method of fastening to the drum, and, other things being equal, should be kept as small as possible. One way would be to key the gear on the outside of the drum, another to bolt the gear to the end of the drum. The latter has the advantage that a standard gear pattern can be used with the slight change of addition of bolt flange on the arms. This makes a simple, direct, and strong drive, the bolts being in shear.

Sketching this arrangement as the preferred one (Fig. 2A), it is evident that the diameter of the gear should be at least as large as the drum in order to keep the tooth load down to a reasonable figure. On the other hand, if made too large, it spreads out the machine and destroys its compactness. As a diameter of 36 inches is not excessive, let us assume this, and see if a desirable proportion of gear tooth can be found to carry the load.

For a pitch diameter of 36 inches there will be a theoretical load of $\frac{5,000 \times 27}{36} = 3,750$ pounds at the pitch line. But the load on the tooth must not only impart a pull of 5,000 pounds to the rope, but must overcome friction between the gear teeth in action, also between the drum shaft and its bearings. Assuming the efficiency between the rope and tooth load to be 95 per cent, the net load, therefore, which the tooth must take is $\frac{3,750}{.95} = 3,947$, say 4,000 pounds.

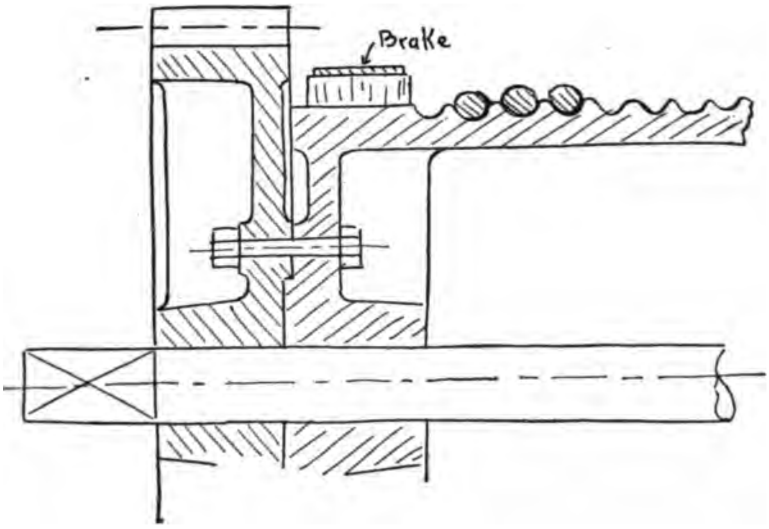


Fig. 2A.

Assuming involute teeth, and applying the "Lewis" formula, (Part II, "Gears"):

$$W = s \times p \times f \times y$$

$$4{,}000 = 6{,}000 \times p \times f \times .116$$

$$p \times f = \frac{4{,}000}{6{,}000 \times .116} = 5.7 \text{ inches}$$

$W = 4{,}000$
$s = 6{,}000$
$y = .116$ (number of teeth assumed at 75)
$p =$ circular pitch
$f =$ face of gear

Let $f = 3\,p$ (a reasonable proportion for machine-cut teeth).

Then $3 \times p^2 = 5.7$

$$p^2 = 1.9$$

$$p = \sqrt{1.9} = 1.378 \text{ inches}$$

The diametral pitch corresponding to this is

$$\frac{3.1416}{1.378} = 2.28$$

which is just between the regular standard pitches, 2 and $2\frac{1}{2}$, for which stock cutters are made. To be safe, let us take the coarser pitch, which is 2. The circular pitch corresponding to this is $\frac{3.1416}{2} = 1.57$, and making the face about three times the circular pitch gives

$$3 \times 1.57 = 4.71, \text{ say } 4\tfrac{3}{4} \text{ inches.}$$

The number of teeth in the gear is then $36 \times 2 = 72$. Referring to the value assumed for the tooth factor in calculation above, it is seen that y was based on 75 as the number of teeth, which is near enough to 72 to avoid the necessity of further checking the result.

The pinion to mesh with this gear should be as small as possible in order to get a high-speed ratio between pinion shaft and drum, otherwise an excessive ratio will be required in the pulleys, making the large one of inconvenient size. Small pinions have the teeth badly undercut and therefore weak, 13 teeth being the lowest limit usually considered desirable, for that reason. Choosing that number, we have a pitch diameter of $\frac{13}{2} = 6.5$ in., which is probably ample to take the shaft and key, and still leave sufficient stock under the tooth for strength. If made of cast iron, however, the pinion teeth, on account of the low number, will be narrower at the root than those of the gear of 72 teeth. Yet it was upon the basis of the latter that the pitch was chosen, for it will be remembered that the value of y in the formula was taken at .116. Hence the pinion will be weaker than the gear unless we make it of stronger material than cast iron, of which the large gear is supposed to be made. Steel lends itself very readily to this requirement; and in practice, pinions of less than 20 teeth are usually made of this material, hence we shall specify the pinion to be of steel.

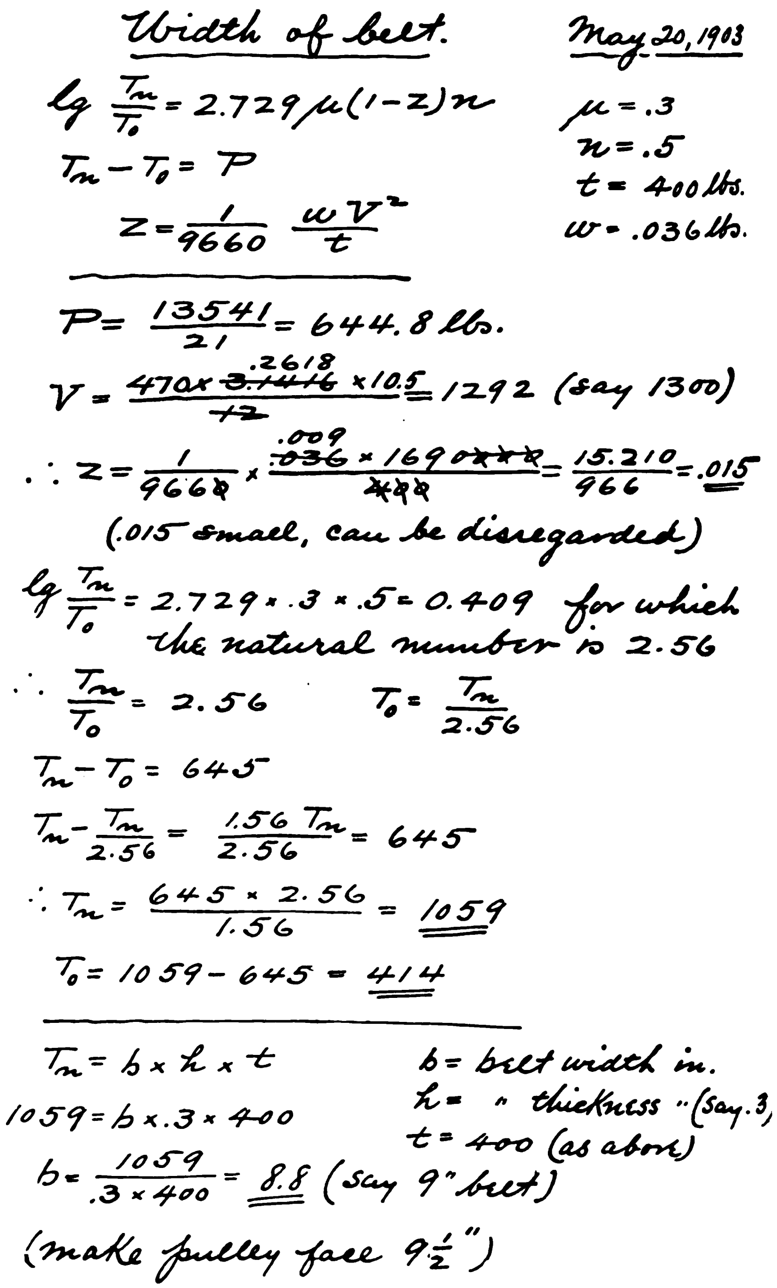
Pulleys. The question now is whether or not we can get a suitable ratio in the pulleys without making the large one of inconvenient size, or giving the motor too slow speed for an economical proportion.

Suppose we limit ourselves to a diameter of 42 inches for the large pulley, and try a ratio of 4 to 1; this will give a diameter for the small pulley of $\frac{42}{4}=10\frac{1}{2}$ inches. We shall then have

Total ratio between drum and motor........	$\frac{72}{13}\times 4=\frac{288}{13}=22.2$
Rev. per min. of drum to give 150 f. p. m. of rope	$\frac{150}{7.07}=21.2$
Rev. per min. of motor..........................	$22.2\times 21.2=470$
Horse-power of motor at 80 per cent efficiency	$\frac{150\ \times 5{,}000}{33{,}000\times\ .80}=30$

A 30 H. P. motor running 470 r. p. m. would be classed as a slow speed motor and would be a heavier machine and cost more than one of higher speed. It will be noticed, however, that the diameter of the small pulley is already quite reduced, and it is hardly desirable to decrease it still further. Neither can we increase the large pulley, as we have already set the limit at 42 inches. Hence, for our present problem we cannot improve matters much without increasing the size of the large gear, which is undesirable, or putting in another pair of gears, which is contrary to the conditions of the problem. As such a motor is perfectly reasonable, we shall assume it to be chosen for the purpose.

In commercial practice it would be well to pick out some standard make of motor of the required horse-power, note the speed as specified by the makers, and then, if possible, suit the ratio in the machine to this speed. It is always best to use standard machinery, if possible, both from the standpoint of first cost, as well



Width of belt. May 20, 1903

$lg \frac{T_n}{T_0} = 2.729 \mu (1 - z) n$

$T_n - T_0 = P$

$z = \frac{1}{9660} \frac{w V^2}{t}$

$\mu = .3$
$n = .5$
$t = 400$ lbs.
$w = .036$ lbs.

$P = \frac{13541}{21} = 644.8$ lbs.

$V = \frac{470 \times \overset{.2618}{\cancel{3.1416}} \times 10.5}{\cancel{12}} = 1292$ (say 1300)

$\therefore z = \frac{1}{966\cancel{0}} \times \frac{\overset{.009}{\cancel{.036}} \times 1690\cancel{000}}{\cancel{400}} = \frac{15.210}{966} = \underline{\underline{.015}}$

(.015 small, can be disregarded)

$lg \frac{T_n}{T_0} = 2.729 \times .3 \times .5 = 0.409$ for which the natural number is 2.56

$\therefore \frac{T_n}{T_0} = 2.56 \qquad T_0 = \frac{T_n}{2.56}$

$T_n - T_0 = 645$

$T_n - \frac{T_n}{2.56} = \frac{1.56\, T_n}{2.56} = 645$

$\therefore T_n = \frac{645 \times 2.56}{1.56} = \underline{\underline{1059}}$

$T_0 = 1059 - 645 = \underline{\underline{414}}$

$T_n = b \times h \times t$

$1059 = b \times .3 \times 400$

$b = \frac{1059}{.3 \times 400} = \underline{\underline{8.8}}$ (say 9" belt)

b = belt width in.
h = " thickness " (say .3)
t = 400 (as above)

(make pulley face $9\frac{1}{2}$")

Fig. 3.

as ease of replacing worn parts. Machinery ordered special is expensive in first cost of designing, patterns, and tools, and extra spare parts for emergency orders are not often kept on hand.

Tabulation of Torsional Moments. For future reference, it is desirable at this point to tabulate the torsional moment, or torque, about each of the three shaft axes, assuming reasonable efficiencies for the various parts, as follows:

Efficiency between drum and gear tooth.............95 per cent
Efficiency between drum and pinion shaft...........90 per cent
Efficiency between drum and motor shaft...........80 per cent

TABLE OF TORSIONAL MOMENTS.

Axis.	Inch Lbs. Torque at 100 Per Cent Efficiency.	Inch Lbs. Torque, Efficiency as Above.
Drum......	$5{,}000\times\frac{27}{2}$ ....$=67{,}500$	$\frac{67{,}500}{.95}=71{,}052$
Pinion......	$5{,}000\times\frac{27}{2}\times\frac{13}{72}$ ......$=12{,}187$	$\frac{12{,}187}{.90}=13{,}541$
Motor......	$5{,}000\times\frac{27}{2}\times\frac{13}{72}\times\frac{10.5}{42}=3{,}047$	$\frac{3{,}047}{.80}=3{,}809$

This means that the motor develops a torque of 3,809 inch-pounds delivering to pinion shaft 13,541 inch-pounds, and to drum 71,052 inch-pounds.

Width of Belt. The page of calculation for belt width is reproduced in Fig. 3.

The calculation as given is strictly scientific, based on the working strength of a cemented joint ($t=400$ lbs. per square inch). This is a favorable situation for the use of a cemented joint, because it is easy to provide means of adjusting the belt tension by placing the motor on a sliding base. Otherwise a laced joint could be used, requiring relacing when the belt slackens through its stretch in service. Under the assumption that a double *laced* belt is used, the empirical formula below is one often applied:

$$\text{H. P.}=\frac{w\times V}{540}=\frac{w\times 1{,}300}{540}=30$$

This gives $w=\frac{540\times 30}{1{,}300}=12{\cdot}4$ inches (say 12 inches).

It should be remembered that this value is purely empirical; it applies to a *laced* joint, and could not be expected to check the value of 9 inches obtained by the first computation for a cemented joint. It is fairly in proportion. For the quite definite service required of the belt in the present case, the width of 9 inches is doubtless sufficient, considering the cemented joint.

Length of Bearings. Considerable latitude in choice of length of bearings is permissible, especially in such slow-speed machinery. There is probably little danger from heating, and the question then becomes one of wear. It is better in such cases as the one in question, to choose boldly a length which seems to be reasonable and proceed with the design on that basis, even if the length be later found out of proportion to the shaft diameter, than to waste too much time in the preliminary calculation over the exact determination of this question. Probably in most cases of commercial practice the existence of patterns, or some other practical consideration, will decide the limits of length.

In the present instance it seems reasonable that a length of 6 inches would fill the requirement for the worst case, that of the drum shaft, and it is obvious that the bearings for the pinion shaft would naturally be of the same length on account of being cast on the same bracket, and faced at the same setting of the planer tool.

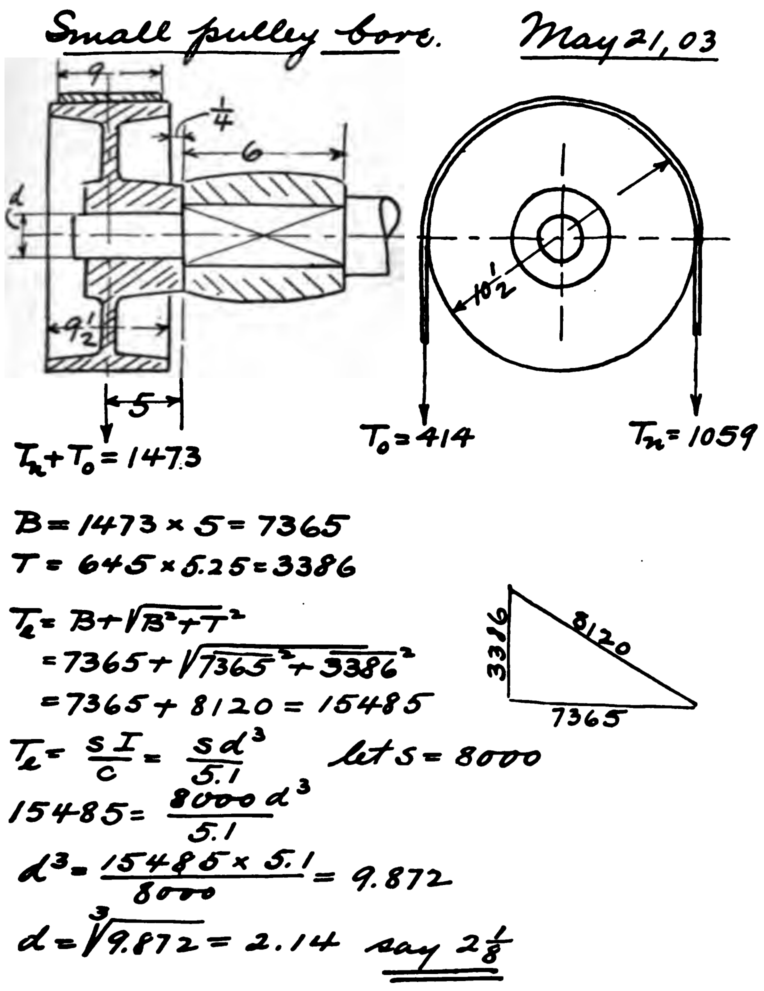
Height of Centers. The large pulley should naturally swing clear of the floor. This will require, say, a total height of 23 inches, out which we may take 4 inches for the base, leaving 19 inches as the height, center of bearing to base of bracket.

Data on Sketch. The data as found above should now be put on the sketch previously made; it will then have the appearance shown in Fig. 1.

This sketch is now in form to control all the subsequent detail design, and it is expected that the figured dimensions as shown can be maintained. It is impossible to predict this with positiveness, however, as in the working out of the minor details certain changes may be found desirable, when, of course, they should be made.

The shaft sizes do not appear on this sketch, hence before proceeding further the several shaft diameters must be calculated.

Sizes of Shafts. The calculations of the shaft diameters are good instances of systematic engineering computations, hence they are reproduced in the exact form in which they were made. The student should learn a valuable lesson in making and recording ulations by following these carefully. Note that each set of ures is independent, both in the statement of given data, as well in the actual computation. Observe how easy it would be for e author of these figures or anyone else to check them even after



Small pulley bore. May 21, 03

$T_o = 414$ $T_n = 1059$

$T_n + T_o = 1473$

$B = 1473 \times 5 = 7365$

$T = 645 \times 5.25 = 3386$

$T_e = B + \sqrt{B^2 + T^2}$

$= 7365 + \sqrt{7365^2 + 3386^2}$

$= 7365 + 8120 = 15485$

$T_e = \frac{sI}{c} = \frac{sd^3}{5.1}$ Let $s = 8000$

$15485 = \frac{8000\,d^3}{5.1}$

$d^3 = \frac{15485 \times 5.1}{8000} = 9.872$

$d = \sqrt[3]{9.872} = 2.14$ say $2\frac{1}{8}$

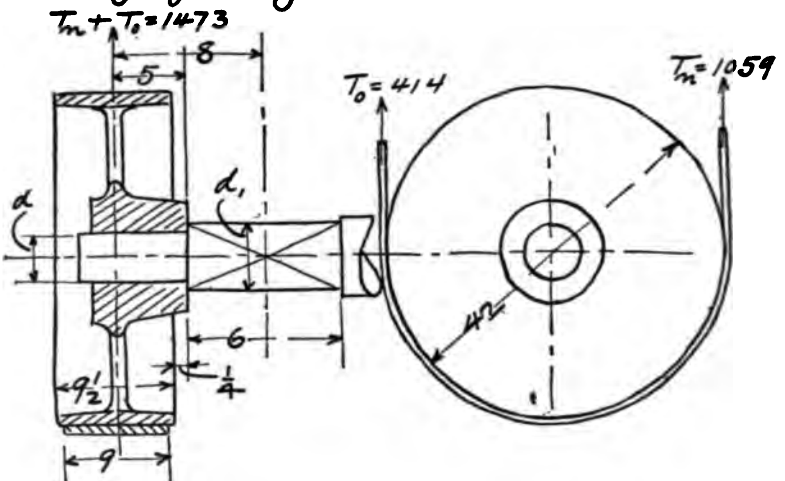
Fig. 4.

a long lapse of time. If the machine should unexpectedly fail in service the figures are always available to prove or disprove theoretical weakness. The right triangles merely indicate that the value of $\sqrt{B^2+T^2}$ was found by the graphical method suggested in

Part II, "Shafts," the figures being put on the triangle as a simple and direct way of recording both process and result.

· Attention is especially called to the fact that in the pinion shaft the size is changed for each piece upon the shaft. This is

Large pulley bore May 21'03.



$$B = 1473 \times 5 = 7365$$
$$T = 644.8 \times 21 = 13541$$
$$T_e = B + \sqrt{B^2 + T^2}$$
$$= 7365 + \sqrt{7365^2 + 13541^2}$$
$$= 7365 + 15425 = 22790$$
$$T_e = \frac{SI}{c} = \frac{Sd^3}{5.1} \quad \text{let } S = 8000$$
$$22790 = \frac{8000\,d^3}{5.1}$$
$$d^3 = \frac{22790 \times 5.1}{8000} = 14.529$$
$$d = \sqrt[3]{14.529} = 2.44 \quad \text{say } \underline{\underline{2\tfrac{7}{16}}}$$

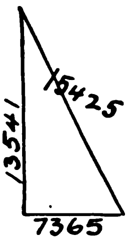


Fig. 5.

done partly because it is desired to show the student that the shaft at each of these points should be theoretically of different size. It is also done because as a practical feature of construction it is a good plan to change the size when the fit changes, partly for reasons of production in the shop, partly for ease in slipping pieces

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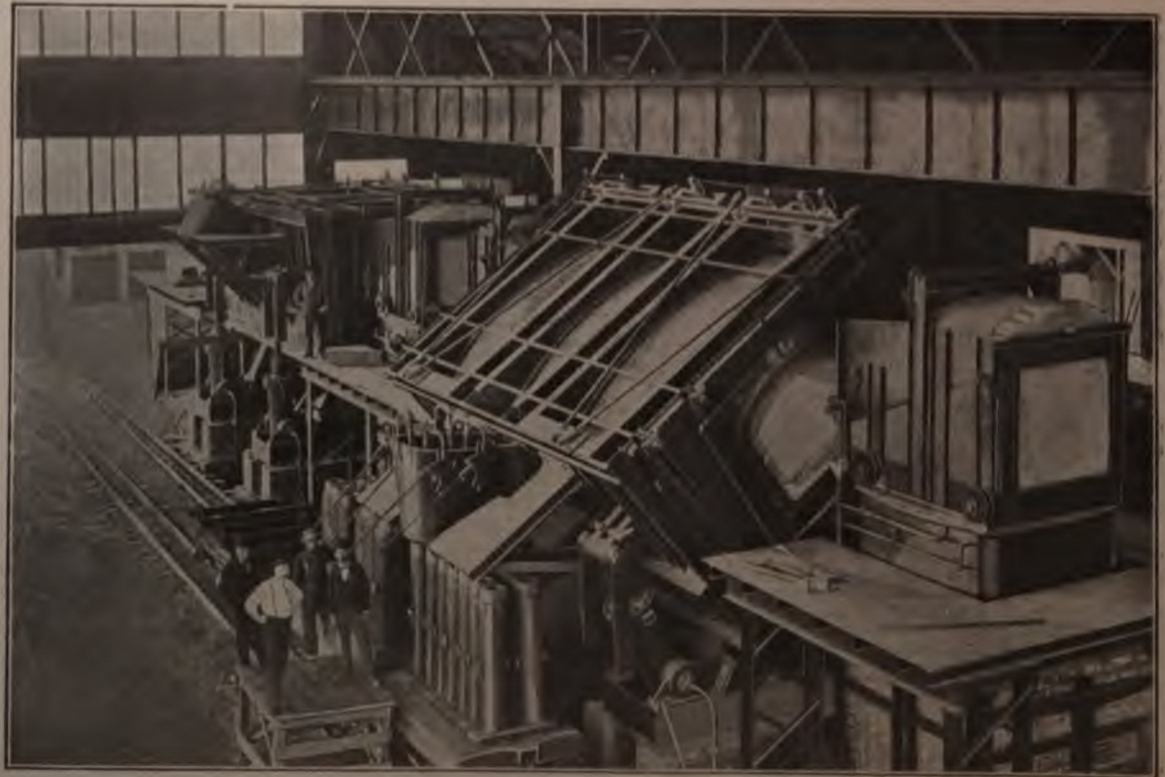


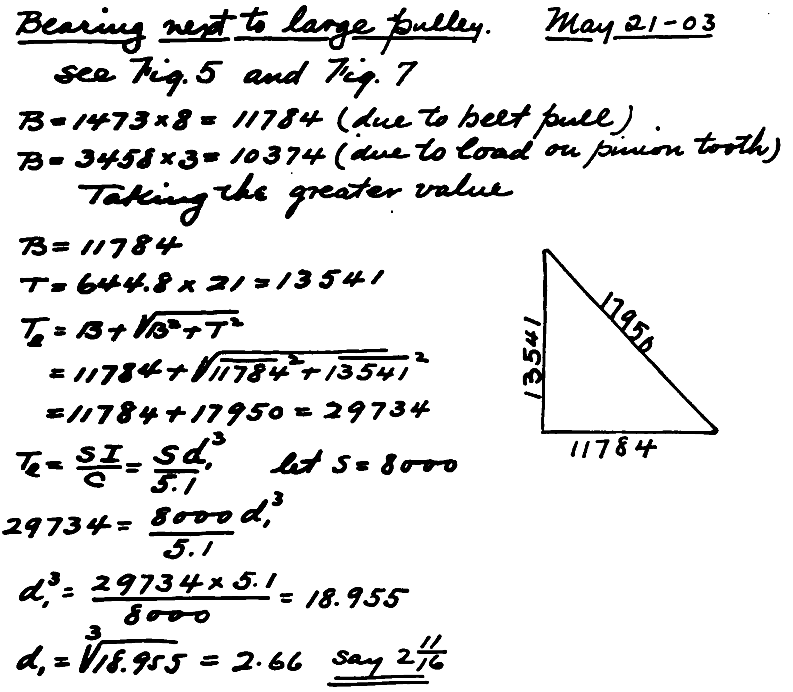
ROLLING OPEN-HEARTH FURNACES

at Hamilton Steel and Iron Co.

The Wellman-Seaver-Morgan Co.

freely endwise on the shaft until they reach their proper fit and location in the assembling of the machine.

This should not be taken as an absolute requirement in any sense. A straight shaft would be satisfactory in the present case; but the shouldered shaft is a little better construction, in a mechanical sense, and does not cost much more. Hence it is used. For the drum the straight shaft seems to answer the requirement well enough.


13541
17950
11784

Bearing next to large pulley. May 21-03

see Fig. 5 and Fig. 7

$B = 1473 \times 8 = 11784$ (due to belt pull).

$B = 3458 \times 3 = 10374$ (due to load on pinion tooth)

Taking the greater value

$B = 11784$

$T = 644.8 \times 21 = 13541$

$$T_e = B + \sqrt{B^2 + T^2}$$

$$= 11784 + \sqrt{\overline{11784}^2 + \overline{13541}^2}$$

$$= 11784 + 17950 = 29734$$

$$T_e = \frac{SI}{C} = \frac{Sd_1^3}{5.1} \quad \text{let } S = 8000$$

$$29734 = \frac{8000}{5.1} d_1^3$$

$$d_1^3 = \frac{29734 \times 5.1}{8000} = 18.955$$

$$d_1 = \sqrt[3]{18.955} = 2.66 \quad \text{say } 2\tfrac{11}{16}$$

Fig. 6.

Small Pulley Bore. Fig 4.

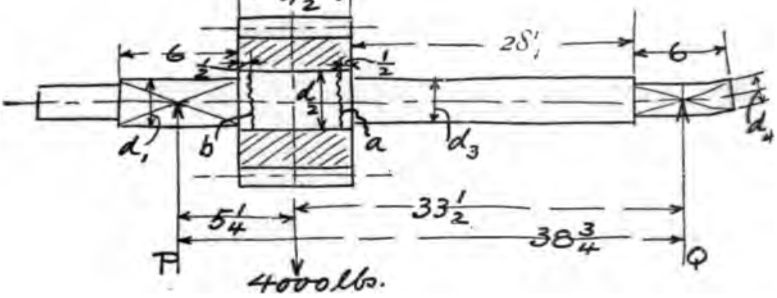
Large Pulley Bore. Fig. 5.

Bearing Next to Large Pulley. Fig. 6.

The diameter, $2\frac{11}{16}$, as calculated, is based on the supposition that the greatest bending moment is caused by the belt pull on the overhanging pulley, that is, by the forces existing at the left-hand side of the center of the bearing.

But the pinion tooth load produces a heavy bending on the shaft in the bearing, the shaft in this case acting as a beam sup-

Pinion Bore May 21 '03



$P \times 38.75 = 4000 \times 33.5$ (moments about Q)

$P = \frac{4000 \times 33.5}{38.75} = 3458$

$Q = 4000 - 3458 = 542$

$B = 542 \times 31.75 = 17208$ (due to Q)

$B = 3458 \times 3.5 = 12103$ (due to P)

Taking the greater value

$B = 17208$

$T = 13541$ (as before)

$T_e = B + \sqrt{B^2 + T^2}$

$= 17208 + \sqrt{17208^2 + 13541^2}$

$= 17208 + 21900 = 39108$

$T_e = \frac{sI}{c} = \frac{s d_2^3}{5.1}$ let $s = 8000$

$39108 = \frac{8000 d_2^3}{5.1}$

$d_2^3 = \frac{39108 \times 5.1}{8000} = 24.928$

$d_2 = \sqrt[3]{24.928} = 2.92$ say $2\frac{15}{16}$

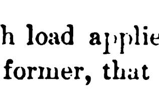


Fig. 7.

ported at the two bearings and having the tooth load applied as shown. If this latter effect be greater than the former, that is, if the bending moment produced by the pinion tooth load be greater than the bending moment produced by the belt pull, then the diameter must be increased to satisfy the latter case. As is seen by the second calculation of Fig. 6, this is not the case, and the diameter stands at $2\frac{1}{16}$ as made.

Pinion Bore. Fig. 7. The pinion being a driving fit upon the shaft, reinforces the shaft to such an extent that it is hardly possible for the shaft to break off very far inside the face of the pinion; but it is quite possible that the metal of the pinion may give enough, or be a little free at the ends of the hole, so that the shaft may be broken off, say $\frac{1}{2}$ inch inside the face. In this case, it may fail from the moment of the force at the left-hand bearing or of that at the right. It may fail then at (a) or (b), depending on which section has the greater bending moment. Trying both, it is seen by the calculation that the right-hand moment is the controlling one, and it, therefore, is used.

Shaft Outside of Pinion. Fig. 8. As there is no power transmitted through this portion of the shaft, there is no torsional moment in it, and the bending moment remains practically the same as inside the pinion.

The size figures about $2\frac{3}{16}$, but since there is no use in turning off material just to reduce the size to this, it is well to make it $2\frac{7}{8}$, or just smaller than the fit in the pinion.

Pinion Shaft Outer Bearing. Fig. 8. This diameter, of course, figures small, as there is no torsion in it, and the bending moment is not heavy. The practical question comes in, however, whether it is advisable to make the outer bracket different from the inner one just on account of this bearing. The commercial answer to this would probably be "No," hence the size as figured next to the pinion will be maintained ($2\frac{1}{16}$).

Drum Shaft. Fig. 9. In this case, as previously inferred, the simplest thing to do is to use a piece of straight cold-rolled steel, and make both bearings alike, the size being determined according to the worst case of loading which can occur as the rope travels from end to end of the drum. This case is evidently when the rope is at the end of its travel close to the brake, for at that time both the load on the rope and the load on the pinion tooth which is driving it are exerted upward, and produce the n at the bearing next to the gear. The analysis of forces his condition is shown in Fig. 9.

Other litions of loading would be when the brake is on and the toot load relieved, but then the resultant of the brake strap tensions would be diagonally downward and would reduce

Shaft outside of pinion. May 22-'03

See sketch of Fig. 7

$B = 542 \times 31.25 = 16937 \qquad T = 0$

$B = \frac{SI}{c} = \frac{Sd_3^3}{10.2} \qquad$ let $S = 8000$

$16937 = \frac{8000\,d_3^3}{10.2}$

$d_3^3 = \frac{16937 \times 10.2}{8000} = 21.594$

$d_3 = \sqrt[3]{21.594} = 2.78$ say $2\frac{13}{16}$

Pinion shaft outer bearing. May 22-'03

See sketch of Fig. 7

$B = 542 \times 3 = 1626 \qquad T = 0$

$B = \frac{SI}{c} = \frac{Sd_4^3}{10.2} \qquad$ let $S = 8000$

$1626 = \frac{8000\,d_4^3}{10.2}$

$d_4^3 = \frac{1626 \times 10.2}{8000} = 2.073$

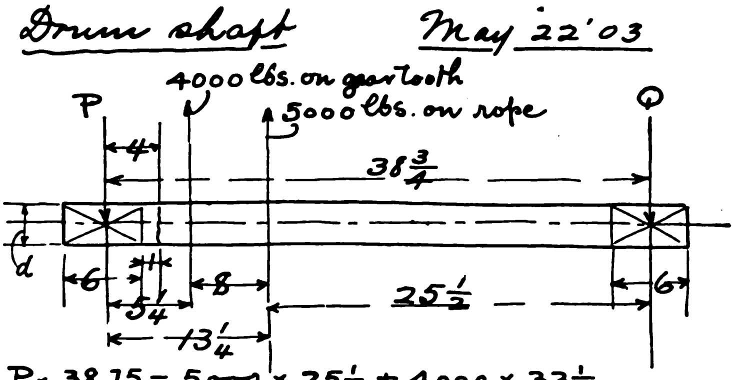
$d_4 = \sqrt[3]{2.073} = 1.27$ say $1\frac{5}{16}$

Fig. 8.

rather than add to the rope load. Again, when the rope is at the end of the drum farthest from the gear, the load on it and the load on the pinion tooth are both exerted upward as before, but the reaction cannot be as great as in the case of Fig. 9, because the tooth load is still concentrated at the other end of the shaft and produces a relatively small reaction at the rope end.

Preliminary Layout. Fig. 10. Proceeding now with the layout to scale, the detail of the parts may be worked out as completely as the scale of the drawing will permit. The work on this drawing may be of an unfinished, sketchy nature, but the measurements must be exact as far as they go, for this drawing is to serve as the reference sheet, from which all future detail is to be worked up.

In this layout may be worked out the sizes of the arms and hubs of pulleys and gears, the proportions of the drum and brake



$$P \times 38.75 = 5000 \times 25\tfrac{1}{2} + 4000 \times 33\tfrac{1}{2}$$

$$P = \frac{261500}{38.75} = 6748$$

$$B = 6748 \times 4 = 26992$$

$$B = \frac{SI}{c} = \frac{Sd^3}{10.2} \quad \text{let } S = 8000$$

$$26992 = \frac{8000\,d^3}{10.2}$$

$$d^3 = \frac{26992 \times 10.2}{8000} = 34.415$$

$$d = \sqrt[3]{34.415} = 3.25 \quad \underline{\text{say } 3\tfrac{1}{4}}$$

Fig. 9.

ap, and the general dimensions of the side brackets and the se. When the detail becomes too fine to work out to advantage on this drawing it may be worked out full size by a separate etch, or left to be finished when it is regularly detailed. The eliminary layout, it should be remembered, is a service sheet ly, a means of carrying along the design, and not intended for

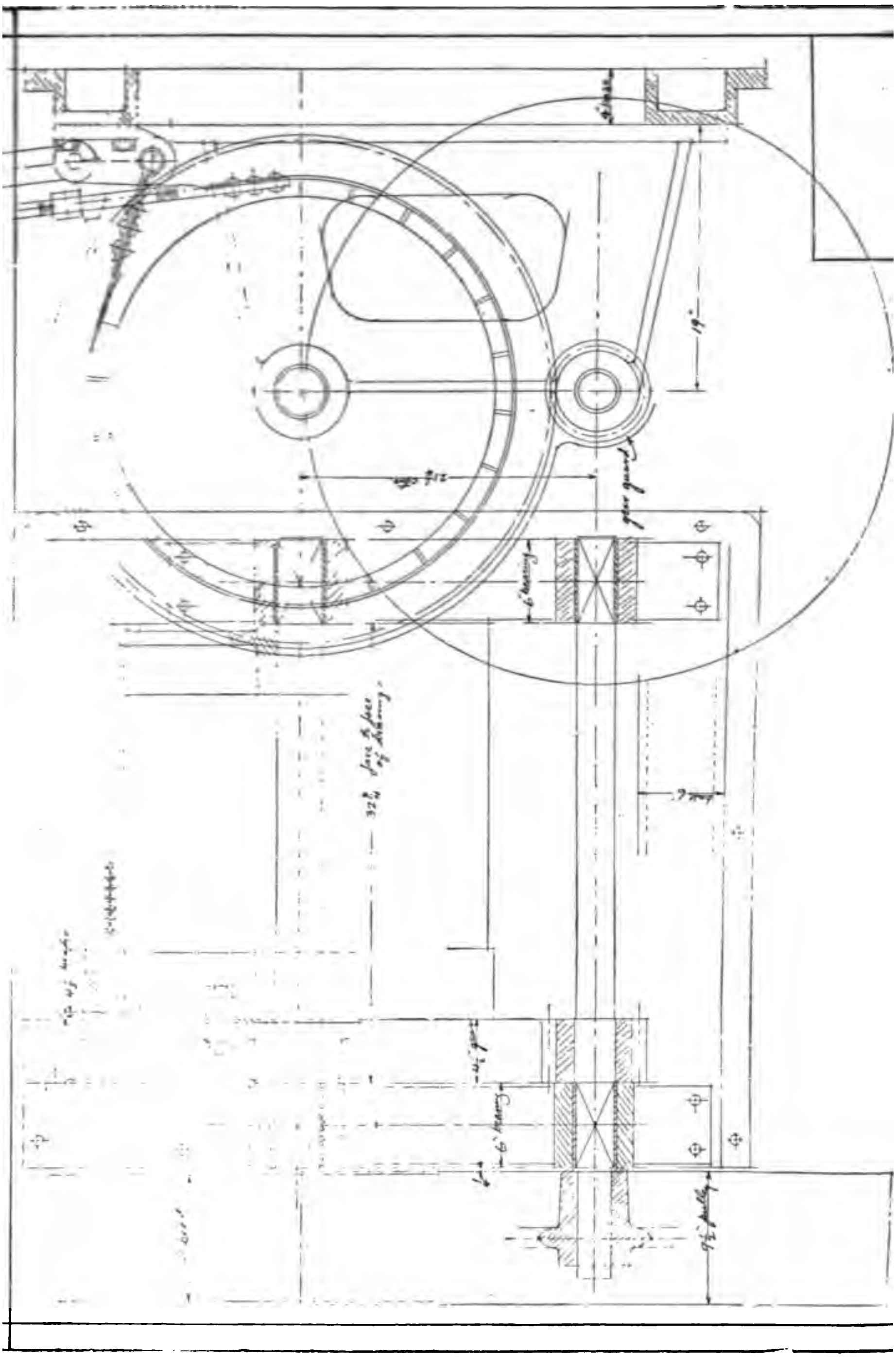

19"
gear guard
6" bearing
17½" pulley
32⅞ face to face of bearing

Fig. 10.

a finished drawing. The moment that the free use of the layout is impaired by trying to make too much of a drawing of it, its value is largely lost. A designer must have some place to try out his schemes and devices, and the layout drawing is the place to do it. This drawing may be recurred to at intervals in the progress of the design, details being filled in as they are worked out, as they may control the design of adjacent parts.

As the discussion of the design of each of the members involved in the present problem can be better taken up in connection with the detail drawing of each, it will be given there, rather than in connection with the layout, although many of the proportions thus discussed could be worked out directly from the latter.

Pulleys. Fig. 11. The analysis of the forces in the belt gives, according to the calculation of Fig. 3, a tension in the tight side of 1,059 pounds, and in the slack side 414 pounds. The difference of these, or 1,059—414=645 pounds, is transmitted to the pulley and produces the torque in the shaft. Of course in the small pulley the torque is transmitted from the motor through the pulley to the belt, but both cases are the same as far as the loading of the pulleys is concerned.

The only other force theoretically acting is the centrifugal force due to the speed of the pulley. This produces tension in the rim and arms, but for the low value of 1,300 feet per minute peripheral velocity in this case may be disregarded.

Considering the arms as beams loaded at the ends, and that one-half the whole number of arms take the load, and for convenience, figuring the size of the arms at the center of the pulley, gives the following calculation for the large pulley:

$$\frac{645}{3}\times 21=\frac{S\times I}{c}=.0393\times 2{,}500\times h^3 \qquad \text{Let } S=2{,}500$$

“ h=breadth of oval

“ $.4h$=thickness of oval

$$h^3=\frac{4.515}{98.25}=46$$

$$h=\sqrt[3]{46}=3.6 \text{ (say 3.5)}$$

$$.4h=.4\times 3\ 5=1.4 \text{ (say 1 7-16)}$$

This is about all the theoretical figuring necessary on this pulley. The rim is made as thin as experience judges it capable of being cast; the arms are tapered to suit the eye, thus giving ample fastening to the rim to provide against shearing off the rim

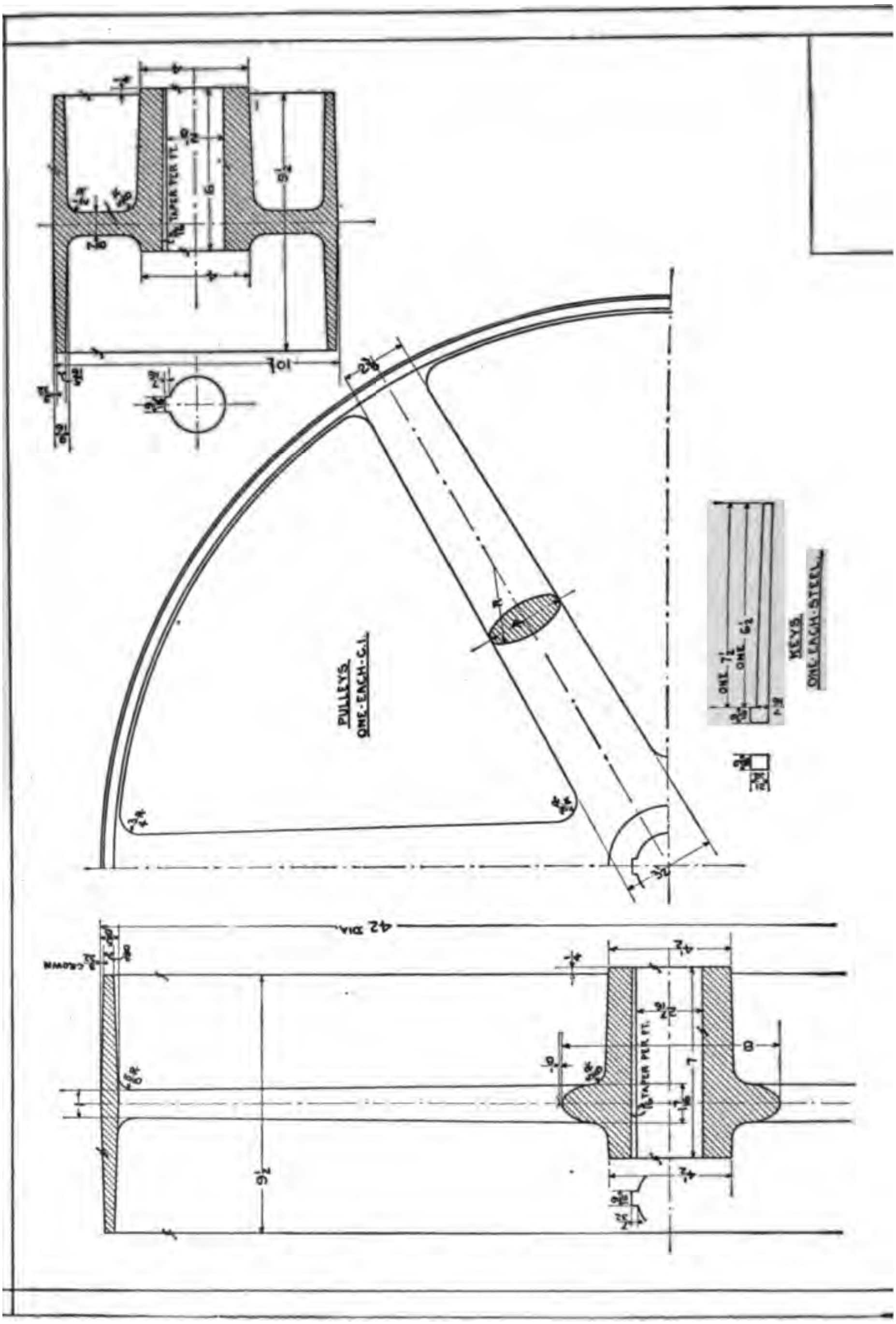

PULLEYS
ONE-EACH-C.I.
KEYS
ONE-EACH-STEEL
ONE
ONE
42 DIA
CROWN
TAPER PER FT.
TAPER PER FT.

Fig. 11.

from the arms; generous fillets join the arms to both rim and hub; and the hub is given thickness to carry the key, and length enough to prevent tendency to rock on the shaft. Uncertain strains due to unequal cooling in the foundry mold may be set up in the arms and rim, but with careful pouring of the metal they should not be serious, and the low value chosen for the fibre stress allows considerable margin for strength.

The small pulley has the same forces to withstand as the large pulley, but on account of its small diameter there is not room enough for arms between the rim and the hub, hence it is made with a web. The web cannot be given any bending by the belt pull, the only tendency which exists in this case being a shearing where the web joins the hub. This shearing also exists throughout the web as well, but at other points farther from the center it is of less magnitude, and moreover, there is more area of metal to take it. The natural way to proportion the thickness of the web is to give it an intermediate thickness between that of the hub and rim, thus securing uniform cooling, and then figure the stress as a check. Making this value $\frac{7}{8}$ inch gives a shearing area of $\frac{7}{8}$ multiplied by the circumference of the hub, which is $3.1416 \times 4 = 12.56$. The shearing force at the hub is $\frac{645 \times 5.25}{2} = 1{,}693$ pounds. Equating the external force to the internal resistance

$$1{,}693 = \tfrac{7}{8} \times 12.56 \times S$$

$$S = \frac{1{,}693 \times 8}{7 \times 12.56} = 154 \text{ pounds per square inch (approx.).}$$

This is a very low figure, even for cast iron, hence the web is amply strong. The rim and hub are proportioned as for the large pulley.

The keys are taken from the standard list. They may be checked for shear, crushing in the hub, and crushing in the shaft, but the hubs are so long that it is at once evident without figuring that the stress would run very low in both cases.

Gears. Fig. 12. The analysis of the forces acting on the gears has been given on page 28, 4,000 pounds being taken at the pitch line. Using this same value, and choosing a T-shaped arm as a good form for a heavily loaded gear like the present one, let us consider that the rim is stiff enough to distribute the load

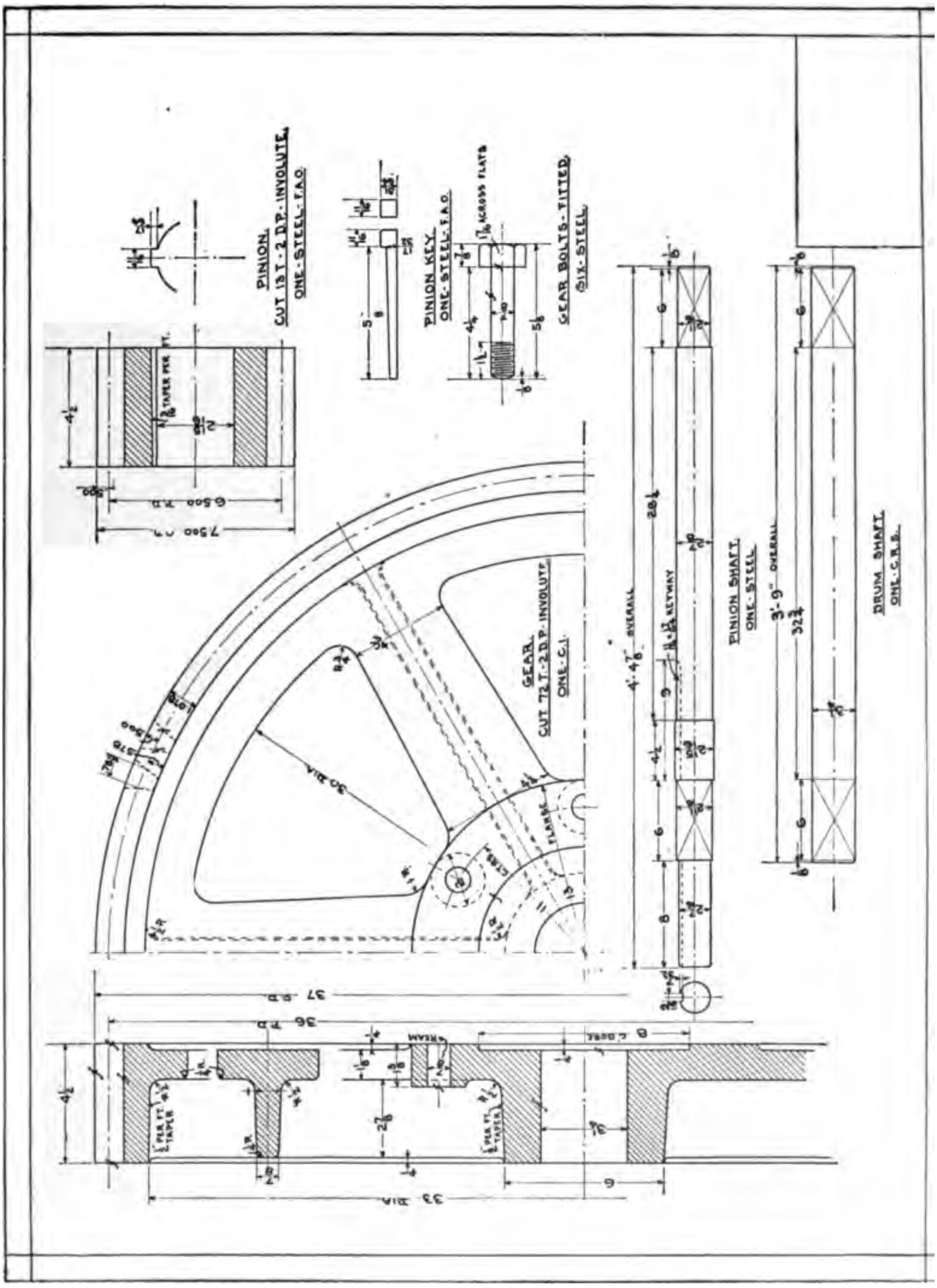

PINION.
CUT 13T-2DP-INVOLUTE.
ONE-STEEL-F.A.O.
PINION KEY.
ONE-STEEL-F.A.O.
GEAR BOLTS-FITTED.
SIX-STEEL.
GEAR.
CUT 72T-2DP-INVOLUTE.
ONE-C.I.
PINION SHAFT.
ONE-STEEL.
DRUM SHAFT.
ONE-C.R.S.
4'-4 7/8" OVERALL
3'-9" OVERALL
30 DIA
33 DIA
36 P.D.
37 O.D.
6.500 P.D.
7.500 O.D.
ACROSS FLATS
KEYWAY
TAPER PER FT.
FLANGE
REAM

Fig. 12.

equally between all the arms, and that each acts as a beam loaded at the end with its proportion of the tooth load. Before we can determine the length of these arms, however, we must fix upon the size of the flange which is to carry the driving bolts. This is taken at 13 inches. It could be smaller if desired, but drawing the bolts in toward the center increases the load on them, and 13 inches seems reasonable until it is proved otherwise. This makes the maximum moment which can come on an arm $\frac{4{,}000 \times 11.5}{6} = 7{,}666$ inch-pounds.

Now it is evident that the base of the T arm section, which lies in the plane of rotation, is most effective for driving, and that the center leg of the T does not add much to the driving capacity of the arm, although it increases the lateral stiffness of the arm, as well as providing in casting a free flow of metal between the rim and the hub. Hence the simplest way of treating the section of the arm for strength is to consider the base of the T only, of rectangular section, breadth b, and depth h, for which the internal moment of resistance is $\frac{S \times b \times h^2}{6}$.

Also, it is simplest to assume one dimension, say the breadth, and the allowable fibre stress, and figure for the depth. Taking the breadth at $1\frac{1}{8}$ inches, which looks about right, and the fibre stress at 2,500, and equating the external moment to the internal, we have

$$7{,}666 = \frac{2{,}500 \times 1.125 \times h^2}{6}$$

$$h^2 = \frac{6 \times 7{,}666}{2{,}500 \times 1.125} = 16.4$$

$$h = \sqrt{16.4} = 4.05 \text{ (say } 4\tfrac{1}{4}\text{)}$$

Drawing in this size, and tapering the arm to the rim as in the case of the pulleys, making the depth of the rim according to the suggested proportions given in Part II, "Gears," giving the center leg of the T a thickness of $\frac{7}{8}$ inch tapering to 1 inch, and heavily filleting the arms to the rim and center flange, we have a fairly well proportioned gear.

The next thing to determine is the size of the driving bolts. The circle upon which their centers lie may be 11 inches in diam-

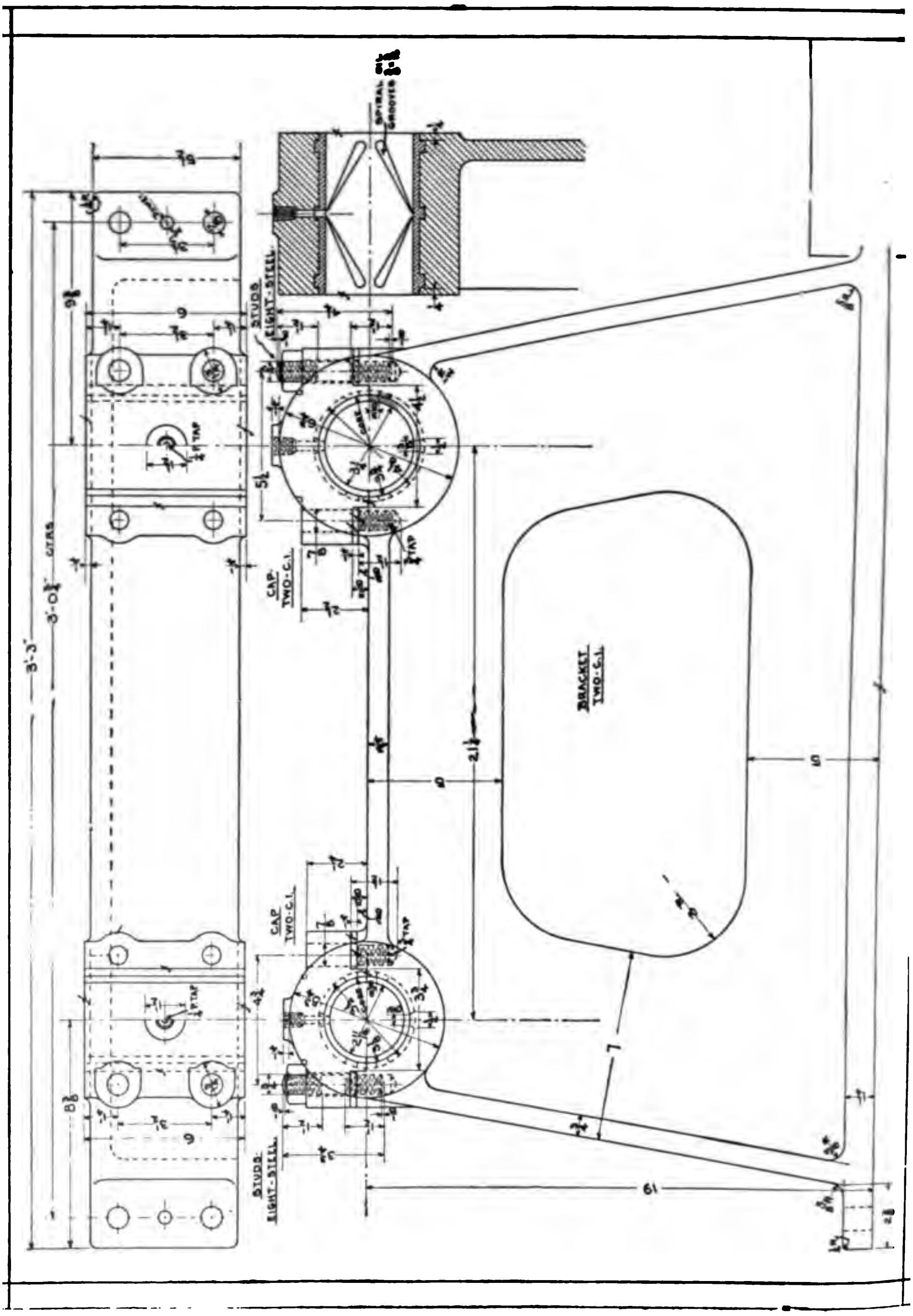

BRACKET
TWO-C.I.
CAP
TWO-C.I.
STUDS
EIGHT-STEEL
SPIRAL GROOVES
3'-3"
3'-0¾" CTRS
21½
19
10
7
TAP

Fig. 13.

eter, and there will naturally be six bolts, one between each arm. These bolts are in pure shear, and the material of which they are to be made ought to be good for at least 8,000 pounds per square inch fibre stress. The force acting at the circumference of an 11-inch circle would be $\frac{4{,}000\times 18}{5.5}=13{,}091$ pounds.

Equating the load on each bolt to the resisting shear gives

$$\frac{13{,}091}{6}=8{,}000\times A=\frac{8{,}000\times 3.1416\times d^2}{4}$$

Let A=area resisting shear.
Let d=dia. of bolt.
Then $A=\frac{\pi d^2}{4}$

$$d^2=\frac{4\times 13{,}091}{6\times 8{,}000\times 3.1416}=.35$$

$d=\sqrt{.35}$ (say .6) $\frac{5}{8}$-inch bolts would do.

But $\frac{5}{8}$-inch bolts are pretty small to use in connection with such heavy machinery. They look out of proportion to the adjacent parts. Hence $\frac{7}{8}$-inch bolts have been substituted as being better suited to the place in spite of the fact that theoretically they are larger than necessary. The extra cost is a small matter. These bolts may crush in the flange as well as shear off, but as there is an area of $\frac{7}{8}\times 1\frac{5}{8}=1.422$ square inches to take $\frac{13{,}091}{6}=2{,}182$ pounds, the pressure per square inch of projected area is only $\frac{2{,}182}{1.422}=1{,}534$ pounds, which is very low.

This gear needs no key to the shaft because all the power comes down the arms and passes off to the drum through the bolts, thus putting no torsional stress in the shaft. The face of the flange is counterbored so as to center the gear upon the drum, without relying upon the fit of the gear upon the shaft to do this.

The pinion is solid and needs no discussion for its design.

Brackets and Caps. Fig. 13. As the size of the drum shaft was determined by considering the rope wound close up to the brake, thus giving in combination with the load on the gear tooth the maximum reaction at the bearing as 6,748 pounds, the cap and bolts should be designed to carry the same load.

For a bearing but 6 inches long, two bolts are sufficient under ordinary conditions and might perhaps do for this case. The load is pretty heavy, however, and it is deemed wise to provide four bolts, thus securing extra rigidity, and permitting the use of bolts of comparatively small size. If the load were distributed equally over all the bolts each would take one-fourth of the whole load, but it is not usually safe to figure them on this basis, because it is difficult to guarantee that each bolt will receive its exact share of stress. Assuming that the two bolts on one side take $\frac{2}{3}$ the whole load instead of $\frac{1}{2}$, which provides for this uncertain extra stress, each bolt must take care of $\frac{1}{3}$ of 6,748, or 2,249, pounds. Allowing 8,000 pounds per square inch fibre stress calls for an area at the root of the thread of $\frac{2{,}249}{8{,}000} = .281$ square inch. Consulting a table of bolts we find that the next standard size of bolt greater than this is $\frac{3}{4}$, which gives an area of .302 square inch.

Choosing this size as satisfactory, the bolts should be located as close to the shaft as will permit the hole to be drilled and tapped without breaking out. A center distance of $5\frac{1}{2}$ inches accomplishes this result. The distance between centers in the other direction is somewhat arbitrary, although the theoretical distance between the bolt and the end of the bearing to give equal bending moment at the center of the cap and at the line of the bolts is about $\frac{5}{24}$ of the length, or $\frac{5}{24}$ of $6 \doteq 1\frac{1}{4}$ inches. This proportion answers well for the present case, although for long caps it brings the bolts too far in to look well.

The thickness of the cap may be determined by assuming it to be a beam supported at the bolts and loaded at the middle. This is not strictly true, for the load is distributed over at least a portion of the shaft diameter; moreover, the bolts to some extent make the beam fixed at the ends. It being impossible to determine the exact nature of the loading, we may take it as stated, supported at the ends and loaded in the middle, and allow a higher fibre stress than usual, say 3,500. The longitudinal section at the middle of the cap is rectangular, of breadth 6 inches, and depth unknown, say h. The equation of moments is

$$\frac{W \times l}{4} = \frac{S \times I}{c} = \frac{S \times b \times h^2}{6}$$

$$\frac{6{,}748 \times 5.5}{4} = \frac{3{,}500 \times 6 \times h^2}{6}$$

$$h^2 = \frac{6 \times 6{,}748 \times 5.5}{4 \times 3{,}500 \times 6} = 2.65$$

$$h = \sqrt{2.65} = 1.62 \text{ (}1\tfrac{1}{2}\text{ will probably answer)}$$

For the other bearing next to the pinion, the load on the tooth cts downward, and the resultant pull of the belt is nearly horiontal, hence the cap and bolts must stand but little load, and alculation would give minute values. In a case like this it is ell to make the size the same as for the larger bearing, unless he construction becomes very clumsy thereby. This saves changing drills and taps in making the holes, and preserves the symmetry of the bracket. The $\frac{3}{4}$-inch bolts are good proportion for the smaller bearing, hence that size will be maintained throughout.

The body of the bracket is conveniently made with the web at the side and horizontal ribs extending to the outside. The load due to the rope is carried directly down the side ribs and web into the bottom flanges and to the bolts. The analysis of the forces on these bolts is shown in Fig. 14. It is evident from the figure that the resultant belt pull tends to hold the bracket down, while the load on the rope tends to pull it up, the point about which it tends to rotate being the corner furthest from the drum. It is also evident that the bolts nearest this corner can have little effect on the holding down, because their leverage is so small about the corner, hence we shall assume that the pair of bolts at the right-hand end of the bracket takes all the load. The belt pull, being horizontal, tends to slide the bracket along the base, but this tendency is small, and at any rate is easily taken care of by the two dowel pins, which are thus put in shear.

The load on the bolts being 4,954 pounds, a heavy bending moment is thrown on the flange of the bracket, tending to break it off at the root of the fillet. The distance to the root of the fillet is $\frac{3}{4}$ inch; the section tending to break is rectangular, of breadth $5\frac{1}{2}$ inches, and unknown depth h. The equation of moments is

$$\mathrm{W}\times l=\frac{\mathrm{S}\times\mathrm{I}}{c}=\frac{\mathrm{S}\times b\times h^2}{6}$$

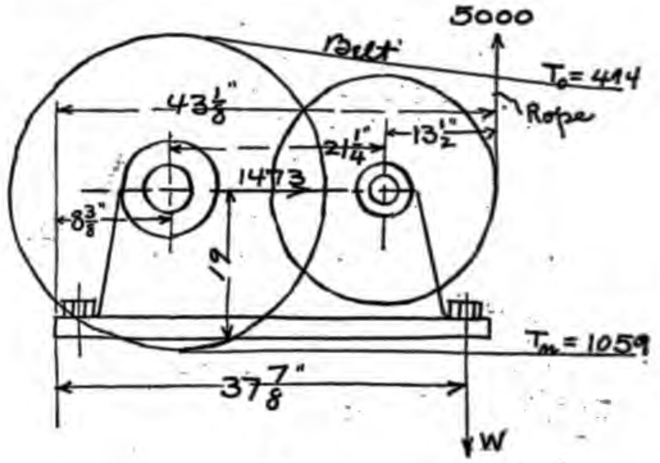
$$\frac{4{,}954\times 3}{4}=\frac{2{,}500\times 5.5\times h^2}{6}$$

$$h^2=\frac{6\times 4{,}954\times 3}{4\times 2{,}500\times 5.5}=1.62$$

$$h=\sqrt{1.62}=1.3\ (\text{say }1\tfrac{1}{4}).$$

The thickness of the web and ribs of this bracket is hardly capable of calculation. The figure $\frac{3}{4}$ inch has been chosen in proportion to the size of the large drum bearing, giving ample stiffness and rigidity, and permitting uniform flow and cooling of the metal in the mold. The opening in the center is made merely to save material, as in that part little stress would exist, the two sides

Bracket base bolts May 25-1903



$$5000 \times 43\tfrac{1}{8} = 37\tfrac{7}{8} \times W + 1473 \times 1.9$$

$$W = \frac{5000 \times 43.125 - 1473 \times 19}{37.875}$$

W = 4954 lbs on two bolts

$\frac{4954}{2} = 2477$ lbs per bolt.

$\frac{2477}{8000} = .31$ sq. in. area at 8000 fib. stress.

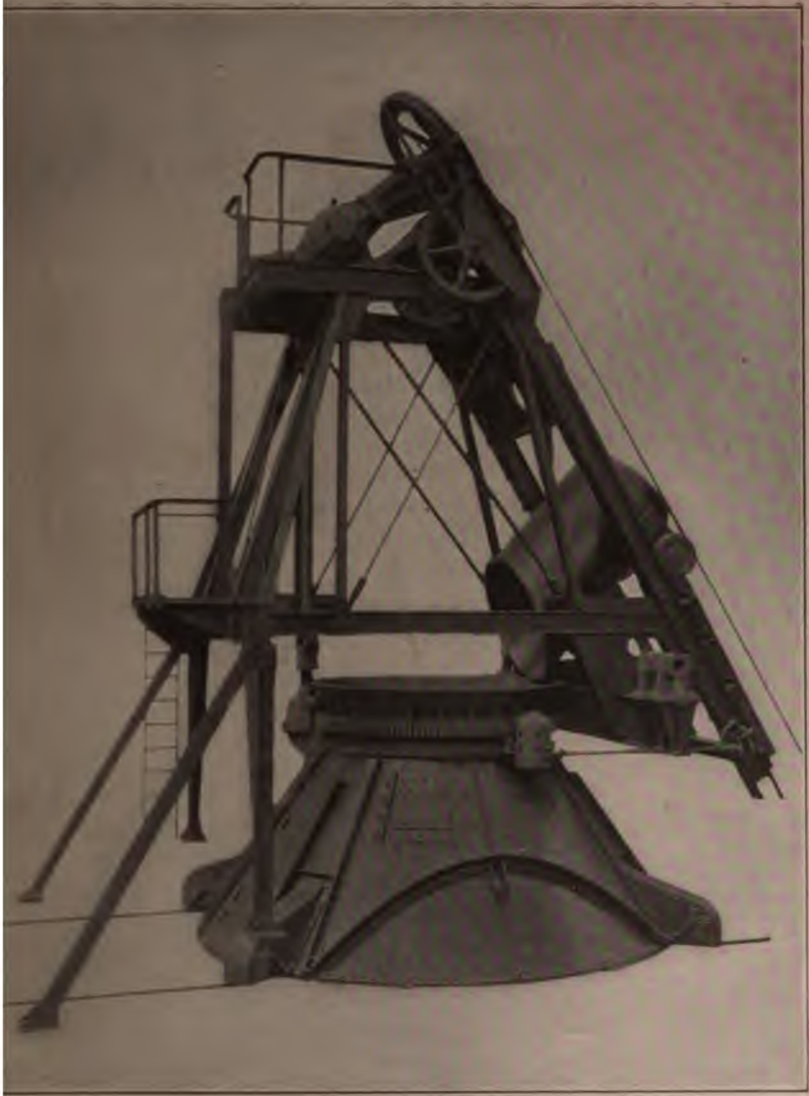
Area at root of thread for a $\frac{3}{4}$ bolt is .28

Hence $\frac{3}{4}$ bolts will answer.

Fig. 14.

carrying the load down to the base bolts, and the top serving as a tie between the bearings.

This bracket might be made with the web in the center of the bearings instead of at the side, in which case the expense of the



FURNACE-HOIST AND STOCK DISTRIBUTOR.
Showing Skip-Car Dumping into Distributor.
Brown Hoisting Machinery Co.

pattern would be slightly greater. It could also be made of closed box form, but would in that case probably weigh more than as shown.

Drum and Brake. Fig. 15. The analysis of the forces acting on the drum is simple, but its theoretical design is more complicated. It is evident that the drum acts as a beam of hollow circular cross section, and that its worst case of loading is when the rope is at or near the middle of the drum length. At the same time the metal of this circular cross section is in a state of torsion between the free end of the rope and the driving gear, due to the load on the gear tooth and the reaction of the rope. Also the wrapping of the rope around the drum tends to crush the metal of the section beneath it, the maximum effect of this action being near the free end of the rope where its tension has not been reduced by friction on the drum surface.

Now the "mechanics" to solve the problem of these three combined actions is rather complicated. It can be at least approximately solved, however, for it satisfies fairly well the case of combined compression and shear. But on a further study of this particular case, it is seen at once that the diameter of the drum is relatively large with respect to its length, which means that the thickness of the metal may be very small and yet give a large resisting area, or value of "I," both in direct bending as well as torsion; also it is so short that the external bending moment will be small. The practical condition now comes in, that the drum can be safely cast only when the thickness of the metal is at a minimum limit, for the core may be out of round, not set centrally, or by some other variation produce thin spots or even develop holes reaching out into the rope groove, discovered only when the latter is turned in the lathe.

Hence it seems reasonable and safe in this case to make the thickness of the drum depend simply upon the crushing caused by the wrapping of the rope around it, and we shall take the coil nearest the free end of the rope, assuming that it carries the full load of 5,000 pounds throughout one complete wrap around the drum.

The area resisting the crushing action may be considered to be that of the cross section of a ring, of width equal to the pitch

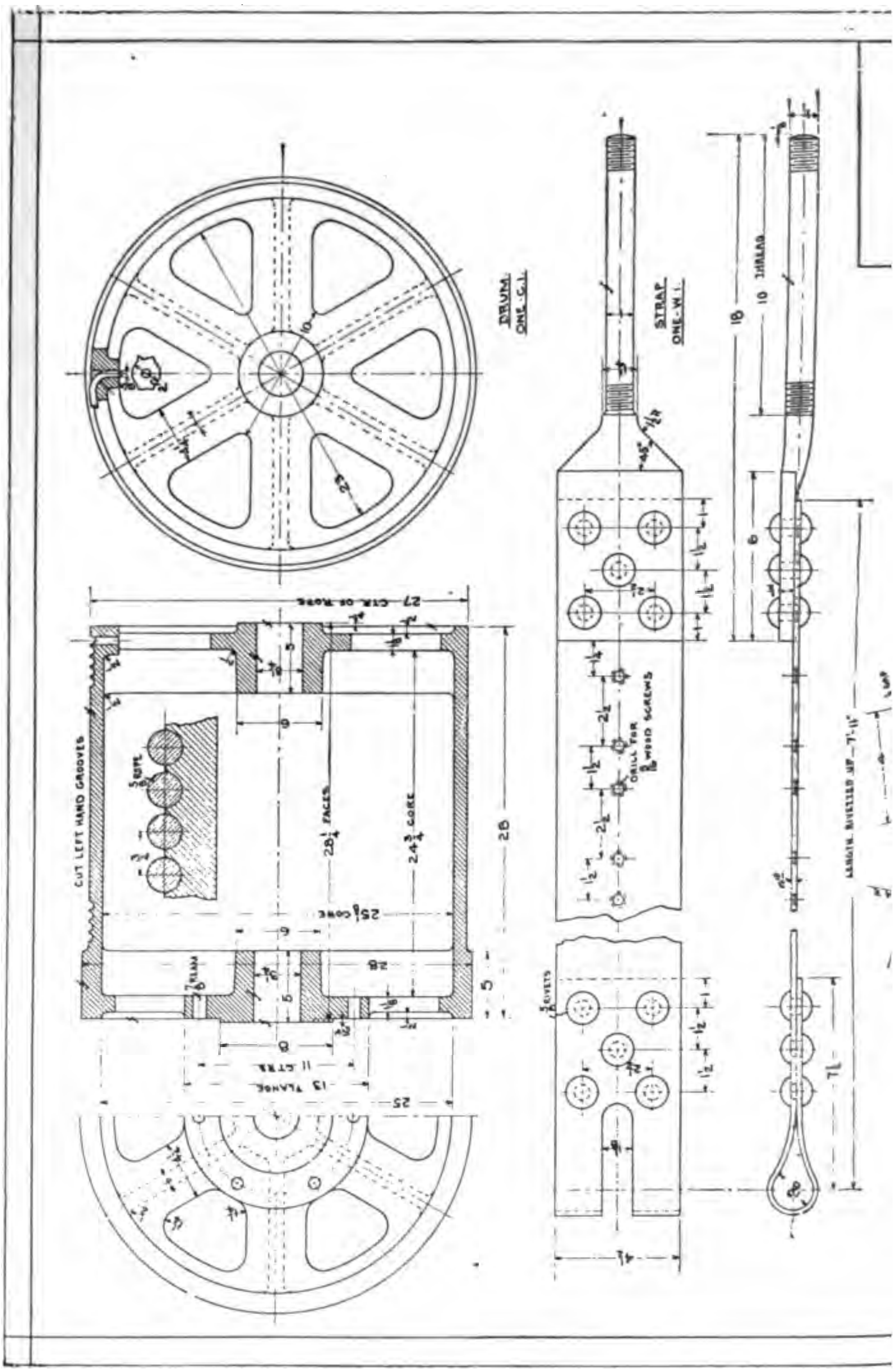

DRUM.
ONE-C.I.
STRAP
ONE-W.I.
CUT LEFT HAND GROOVES
DRILL FOR 3/8 WOOD SCREWS
10 THREAD
LENGTH RIVETED UP—7'-11"
27 CTR. OF ROPE
28 1/4 FACES
24 3/4 CORE
25 5/8 CORE
28
25
11 CTRS
13 FLANGE
18
6
5/8 RIVETS

Fig. 15.

of the groove. Assuming that $\frac{5}{8}$ inch is the least thickness which can be safely allowed under the groove for casting purposes, let us figure the crushing fibre stress to see if this is sufficiently strong. Disregarding the small amount of metal existing above the bottom of the groove, this gives the area to resist the crushing $\frac{5}{8} \times \frac{3}{4} = \frac{15}{32}$, or .47 inch. Since there are two of these sections and the rope acts on both sides, the equation of forces is:

$$5{,}000 \times 2 = S \times .47 \times 2$$

$$S = \frac{5{,}000 \times 2}{.47 \times 2} = 10620 \text{ pounds per square inch.}$$

This, for cast iron, in pure crushing, allows plenty of margin for the extra bending and torsional stress, which for such a considerable thickness would be slight.

The above case indicates a method of reasoning much used in designing machinery, which while following out the specified routine of thought as previously given in these pages, stops short of elaborate and minute theoretical calculation when such is obviously unnecessary. If a drum of great length were to be designed, and of small diameter, the same method of reasoning would deduce the fact that the design should be based on the bending and the torsional moments, the thickness in such a case being so great to withstand these that the intensity of the crushing due to wrap of the rope becomes of inappreciable value.

The remaining points of design of the drum are determined from practical considerations and judgment of appearance. The ribs behind the arms are put in to give lateral stiffness and guard against endwise collapse. The arms are subject to the same bending as those of the gear, but as they are equally heavy it is not necessary to calculate them. The flange at the driving end is of course matched to that already designed for the gear. The rope is intended to be brought through the right-hand end with an easy bend and the standard form of button wedged on to prevent its pulling through.

This drum would probably be cast with its axis vertical, and the driving flange down to secure sound metal at that point. Heavy risers would be left at the other end to secure soundness where the rope is fastened. Drums are often cast with the axis horizontal, but the vertical method is more certain to produce a sound casting. The grooves should be turned from the solid metal, partly because it is a difficult matter to cast them, but principally because the rope should run on as smooth surface as possible to avoid undue wear. On drums which carry chain instead of wire rope the grooves are sometimes cast with success, although even in this case the turned groove is generally preferable.

The brake consists of a wrought-iron band to which are fastened wooden blocks, the iron band giving the requisite strength while the blocks give frictional grip on the drum surface and can be easily replaced when worn. As in the designing of a belt the object in view is the grip on the pulley surface by the leather to enable power to be transmitted from the belt to the pulley, so in the case of the brake if we put the proper tension in the strap it can be made to grip the brake drum so tightly that motion between it and the drum cannot occur. The latter case is really the reverse of the first, if the driven pulley be considered, but is identical with the case of the driving pulley, in which the power is transmitted from the pulley to the belt. Of course in the case of the brake no power is transmitted, as when the brake holds no motion occurs, but the principle of the relative tensions in the strap is the same as for the belt.

Since the brake drum surfacs is 28 inches in diameter, the load at that surface which the brake must hold is

$$P = \frac{5,000 \times 27}{14 \times 2} = 4,821 \text{ pounds.}$$

We have then the following calculation corresponding exactly to that of the belt given in Fig. 3.

$\log. \frac{T_n}{T_o} = 2.729 \times \mu \times n$ Let $\mu = .25$

" $n = .75$

$T_n - T_o = P = 4,821$

$\log. \frac{T_n}{T_o} = 2.729 \times .25 \times .75 = 0.512$ (for which the natural number is 3.25).

Then $\frac{T_n}{T_o} = 3.25$ $T_o = \frac{T_n}{3.25}$

$T_n - T_o = 4,821$ $T_n - \frac{T_n}{3.25} = \frac{2.25 \times T_n}{3.25} = 4,821$

$T_n = \frac{4,821 \times 3.25}{2.25} = 6,963$ pounds (say 7,000)

$T_o = 6,963 - 4,821 = 2,142$ pounds (say 2,200)

The tight end of the strap must then be capable of carrying a load of 7,000 pounds, and since the width has already been taken at $4\frac{1}{2}$ inches, the problem is to find the necessary thickness. Equating the external load to the internal resistance we have

$7{,}000 = A \times S$ Let t = thickness

" S = fibre stress $= 12{,}000$

$$7{,}000 = 4.5 \times t \times 12{,}000$$

$$t = \frac{7{,}000}{4.5 \times 12.000} = .13 \text{ inch}$$

This, however, can be but a preliminary figure, for the riveting of the strap will take out some of the effective area, and the thickness will have to be increased to allow for this. Suppose on the basis of this figure we assume the thickness at a slightly increased value, say $\frac{3}{16}$ inch, and proceed to calculate the rivets.

A group of five rivets will work in well for this case, which gives $\frac{7{,}000}{5} = 1{,}400$ pounds per rivet. A safe shearing fibre stress is 6,000, hence the area necessary per rivet is $\frac{1{,}400}{6{,}000} = .23$ square inch. This comes nearest to the area $\frac{9}{16}$ diameter, but for the sake of using the more general size of rivet ($\frac{5}{8}$ inch) the latter is chosen, for which the area is .30.

We must now try these rivets in a $\frac{3}{16}$-inch plate for their safe bearing value. The projected area of a $\frac{5}{8}$-inch hole in a $\frac{3}{16}$-inch plate is $\frac{5}{5} \times \frac{3}{16} = .117$ square inch. $\frac{1{,}400}{.117} = 11{,}965$ (15,000 would be safe)

Taking out two $\frac{5}{8}$-inch rivets from the full width of $4\frac{1}{2}$ inches leaves $4\frac{1}{2} - (2 \times \frac{5}{8}) = 3.25$, and makes the net area of strap to take stress $3.25 \times \frac{3}{16} = .61$ square inches. Re-calculating the fibre stress for this area gives

$$7{,}000 = .61 \times S$$

$$S = \frac{7.000}{.61} = 11{,}475$$ (which approximates the previous value of 12,000).

The slack end of the strap has to take but 2,200 pounds, hence a different calculation might be made for this end giving smaller rivets; but as it is impractical to change the thickness of the strap to meet this reduced load, it is well to maintain the same proportion of joint as at the tight end. The spacing of the rivets in both

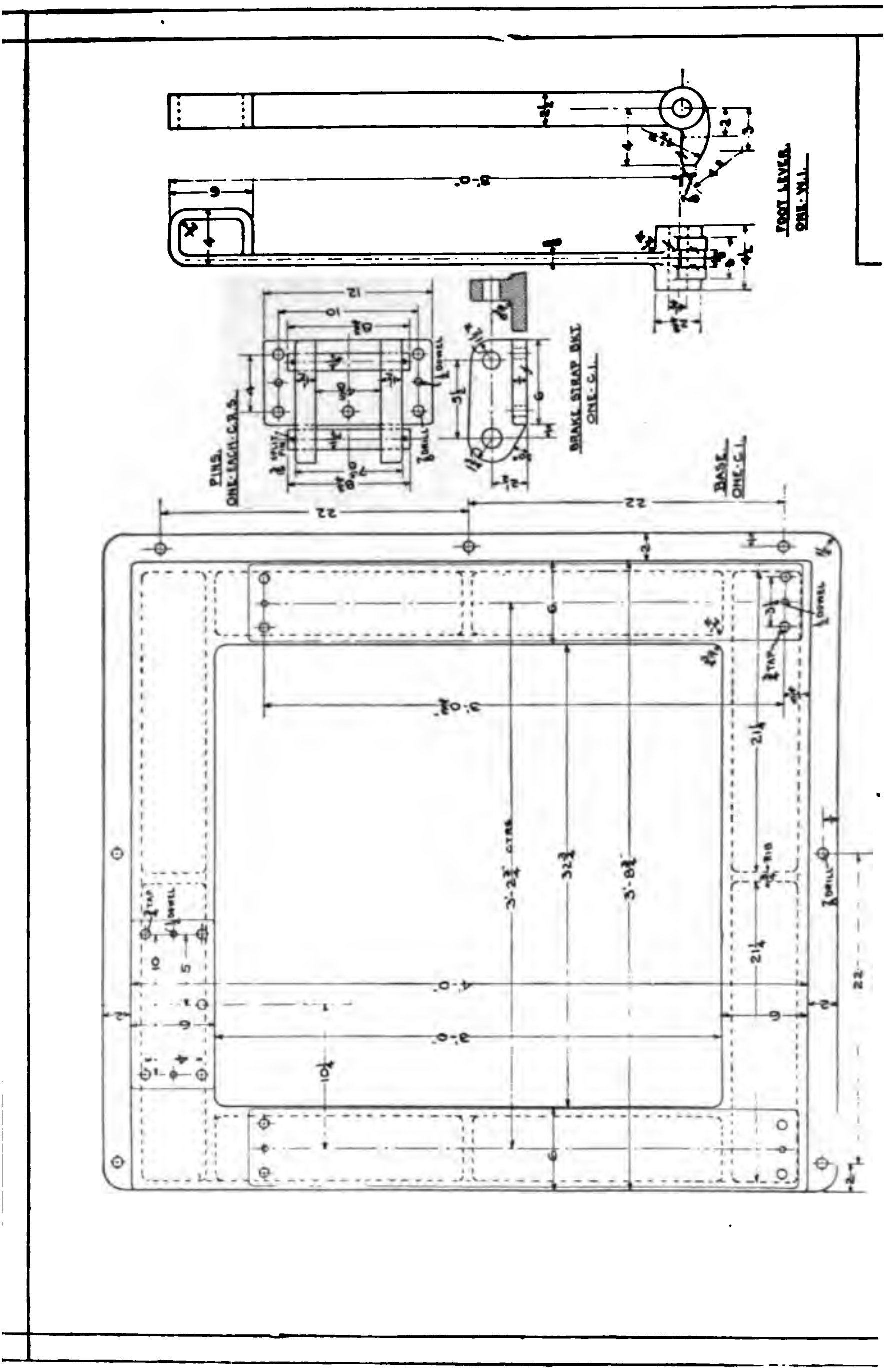

FOOT LEVER. ONE-W.I.
BRAKE STRAP BKT. ONE-C.I.
PINS. ONE EACH-C.R.S.
BASE. ONE-C.I.
3'-2¾" CTRS.
32¾
3'-8¾
4'-0
3'-0
22
21¼
10¼
¾ DOWEL
⅞ DRILL

Fig. 16.

cases follows the ordinary rule allowing at least three times the diameter of the rivet as center distance, and one-half this value to the edge of the plate.

The threaded end of the forging on the strap also has to carry the load of 2,200 pounds, for which a size smaller than 1 inch would suffice. It is natural, however, for the sake of general proportion to make the bolt as strong as the strap, and a 1-inch bolt gives an area of .52 square inch, nearly equalling the value of .61 net area of strap noted above.

Base, Brake-Strap Bracket and Foot Lever. Fig 16. The base cannot be definitely calculated, and can best be proportioned by judgment. It must not distort, twist, or spring in any way to throw the shafts out of line. The area in contact with the foundation upon which it rests must be ample to carry the weight of the whole machine with a low unit pressure. Although the form shown is perfectly practicable to cast and machine, and is simple and rigid, yet it is questionable if a bolted-up construction, say of four pieces, might not be equally rigid and yet involve greater facility of production in both the foundry and machine shop on account of the reduced sizes of parts to be handled. This is a question which depends on the equipment and methods of the individual shop, and is an illustration of the practical control of design by manufacturing conditions.

The brake-strap bracket and foot lever, also shown in this figure, are examples of machine parts which are quite definitely loaded, and the designing of which is a simple matter. Further discussion of their design is not made, the student being given opportunity for some original thought in determining the forces and moments that control their design.

Gear Guard and Brake-Relief Spring. In exposed machinery of this character it is desirable to cover over the gears with a guard to prevent anything accidentally dropping between the teeth and perhaps wrecking the whole machine. This guard is not shown, as it involves little of an engineering nature to interest the student. It could readily be made of sheet metal or light boiler plate, bent to follow the contour of the gears and fastened to the top flange of the main bracket.

If the brake be not automatically supported at its top it will lie with considerable pressure, due to its own weight, on the brake surface when it is supposed to be free from it, and by the friction thereby created will produce a heavy drag and waste of power. A spring connection fastened to an overhead beam is a simple way of accomplishing the desired result. A flat supporting strap carried out from the gear guard, having some degree of spring in it, is a neater method of solving the problem. The spring should be just strong enough to counterbalance the weight of the strap and yet not resist to an appreciable degree the force applied to throw the brake on.

GENERAL DRAWING.

The last step in the process of design of a machine is the making of the assembled or general drawing. This should be built up piece by piece from the detail drawings, thereby serving as a last check on the parts going together. This drawing may be a cross section or an outside view. In any case it is not wise to try to show too much of the inside construction by dotted lines, for if this be attempted, the drawing soon loses its character of clearness, and becomes practically useless. A general drawing should clearly **hint at, but not specify,** detailed design. It is just as valuable a part of the design as the detail drawing, but it cannot be made to answer for both with any degree of success. A good general drawing has plenty of views, and an abundance of cross sections, but few dotted lines.

The general drawing of the machine under consideration is left for the student to work up from the complete details shown. It would look something like the preliminary layout of Fig. 10, if the same were carefully carried out to finished form. A plain outside view would probably be more satisfactory in this case than a cross section, as the latter would show little more of value than the former. The functions which the general drawing may serve are many and varied. Its principal usefulness is, perhaps, in showing to the workman how the various parts go together, enabling him to sort out readily the finished detail parts and assemble them, finally producing the complete structure. Otherwise the making of a machine, even with the parts all at hand, would be like the putting together of the many parts of an intricate puzzle, and much time would be wasted in trying to make the several parts fit, with perhaps never complete success in giving each its absolutely correct location.

The general drawing also gives valuable information as to the total space occupied by the completed machine, enabling its location in a crowded manufacturing plant to be planned for, its connection to the main driving element arranged, and its convenience of operation studied.

In some classes of work it is a convenient practice to letter each part on the general drawing, and to note the same letters on the specification or order sheet, thus enabling the whole machine to be ordered from the general drawings. This is a very excellent service performed by the general drawing in certain lines of work, but for such a purpose the drawing is quite inapplicable in others.

Merely as a basis for judgment of design, the general drawing fulfils an important function in any class of work, for it approaches the nearest possible to the actual appearance that the machine will have when finished. A good general drawing is, for critical purposes, of as much value to the expert eye of the mechanical engineer as the elaborate and colored sketch of the architect is to the house builder or landscape designer.

From the above it is readily understood that the general drawing, although a mere putting together of parts in illustration, is yet of great assistance in producing finished and exact machine design.

GENERAL COMMENTS ON PRECEDING PROBLEM.

After following through the detail of work as given in the preceding pages, it is worth while to stop for a moment and take a brief survey or review of the subject as illustrated therein.

If the text be carefully studied it will be seen that in every part to be designed the same routine method has been followed, regardless of the final outcome. In some cases it may seem a roundabout procedure to follow a train of thought that finally ends in a design apparently based on purely practical judgment, the theory having had but very little if any influence. The question at once arises—Why not use the empirical rule or formula in the first place? Why not make a good guess at once? Why not save all the time and energy devoted to a careful analysis and theory, if we are finally to throw them away and not base our design on them?

The principle to be noted in this connection is, that it is just as fatal to good design to rely upon bare experience and upon judgment alone, as it is to construct solely according to what pure theory tells us. There are many things in the operation of machinery that are totally inexplicable from the purely practical point of view, and will forever remain so until we analyze them and theorize on them. Many good things in machinery have been the result of what might be called "reversed" machine design. When a new machine is started, it frequently, or we might almost say always, fails to do its work just as it is expected to do it. This is because some little point of design is bad, owing to the inability of drawings, however good they may be, to show all that the machine itself in bodily form and in motion shows.

Now, if our analysis and theory have been good in the designing process, it is almost sure that we can very readily analyze and theorize on the trouble that exists when the machine is finished, can detect the weakness, and can correct it with comparatively small change in the general design. This is "reversed" machine design.

If, on the contrary, we have based our design purely on guesswork, allowing our fancy full and free play to work out the details without further basis, we may consider ourselves lucky if the machine runs at all. This, however, is not the worst of the situation. If the machine does actually operate, even as well as it might reasonably be expected to, but still has the usual difficulty of some little kink or hitch that was not expected, then, as a result of the method upon which the whole thing has been constructed, we have no definite plan of action to proceed upon. We must try first this, then that scheme to obviate the trouble. We may be fortunate enough to "strike it" the first time; we may never strike it. It is doubtful if the machine ever can be made to work at highest efficiency; and if fairly good results be finally obtained we never know the reason why, and have nothing on which to base any future action or design.

This haphazard process is not machine design at all, either in name or in result.

As has previously been stated in these pages, there is no such thing as too much analysis or theory in the designing of machinery. Even if we carefully analyze, theorize with rigorous exactness, and then practically modify our construction to such a point that the original theoretical shape is almost or entirely lost, the apparently roundabout process is not in vain, for we are in perfect control of our design. We know exactly what it has to take in the way of forces, blows and vibrations. We know what its ideal shape should be. We know where we can practically modify its form without weakening it excessively or adding excess of material. In other words we know all about it, and therefore know exactly what we can do with it; and whether it follows in its shape the outline that pure theory gives it or some other outline, it is nevertheless well designed.

"Reversed" machine design, as described above, based on observation and experiment with regard to machines already in operation, is just as impossible without exact analysis and theory as is original design based merely on mechanical ideas in the abstract. The method once learned and made a habit of mind will produce results with equal facility in either case, and results are what the mechanical world is seeking.

Another point worth noting in the progress of the problem as given is the absolute necessity of possessing some knowlege of Mechanics. The more of this subject the designer can have at his finger ends, the more ready and successful will he be in all problems of Machine Design. However, the principles of forces and moments clearly understood, and the application of the same in the all-important subject, "Strength of Beams," constitnte a fund of information that will give a splendid start and a good working basis for simple designs. It should always be remembered that a complicated design is little more than a combination of simple designs, and if one has the ability to dissect and analyze what seems at first like a bewildering maze of parts, complication is speedily changed to simplicity.

Common sense goes a long way in good designing. There is nothing mysterious about the process If the beginner will only labor and attention on the part of the operator. This is especially true of automatic machinery, which perhaps might be classed by itself in this respect, but which is nevertheless included under the broad term of a machine for producing finished surfaces, being merely the highest and most refined form of same. For machines of this class the designer has to study every detail with the most minute attention, packing away the operating parts into the smallest space and yet providing ready means for access, removal, and repair. Clearances that would be too little for other kinds of machinery are permitted and provided for; material of high grade, strength, and wearing quality, though expensive in first cost, and requiring the most expert skill to finish and to fit into place, must be used in order to keep the machine compact and yet of large capacity, to make it reasonably light in weight and yet amply strong.

Another point which has a great influence on the design of a machine tool is that we can never tell in advance just what it will have to stand in work, for the variation in the material that it finishes, the uncertain skill of the operator who runs it, the crowding to its limit of capacity and even beyond in times of press of business, and the many other stresses that may suddenly and without warning be thrown upon it, must all be thought of and provided for.

The points above mentioned are but a few of those which the designer of machine tools has to meet, and are presented merely as illustrations to show the special skill required in this class of machinery. It is readily seen that while the machine tool designer has great latitude in choice of material and in expenditure of money for refinement of structure—perhaps greater latitude than in any other class, yet he is held down as in no other to the final productive results, a small percentage of failure entirely throwing out the machine as a marketable product.

The style and external appearance of machine tools have a character of their own resulting from this extreme detailed care in design. Corners and fillets are carefully rounded; surfaces and intersections are definitely made; in short, the mechanical beauty of a machine tool is seen only from a near view and close inspection, and it is to this end that the design is constantly directed Appearance is a large factor in the sale of a fine tool, and the prestige of the American trade abroad in this respect is very noticeable.

Motive-Power Machinery. Examples:—Steam engine, gas engine, air compressor, steam pump, hydraulic machinery, etc., etc.

The element of heat enters into the design of all machinery in this class. The natural agents, air, gas, and water, in their various forms, are taken into the machine in the most efficient form in which it is possible to obtain them, are robbed of their energy to provide power, and are discharged in a form as weak and inert as the efficiency of the machine will determine.

In contrast to the class of machinery just studied, it should be noted that these machines do not produce any material thing; that is, they do not produce finished surfaces on metals, make screws or bolts, bore holes in castings, or turn line shafting. They merely take the energy of the natural agent, which is not in a form available for use, and transform it into motive power for general use.

Hence the element of accuracy as entering into the design of these machines is necessary only for their own efficient operation, and not for the quality of the thing which they produce, as in the case of machine tools. For example, the power furnished by one steam engine to drive a line shaft is as good as that of another as far as the rotating of the shaft is concerned, provided, of course, that both are equipped with the same quality of governing mechanism. The fact that one of the engines has a good adjusting device on the main bearing while the other has not is of no consequence from the standpoint of the line shaft, but it is, of course, of consequence respecting the efficient operation of the engines.

The design of steam engines and similar machines is of a rough nature compared with that of machine tools, as far as the detail of surface is concerned. General accuracy is nevertheless essential for the machine's own sake, but while in the machine tool we deal with thousandths of an inch, in the steam engine hundredths of an inch indicates fine work.

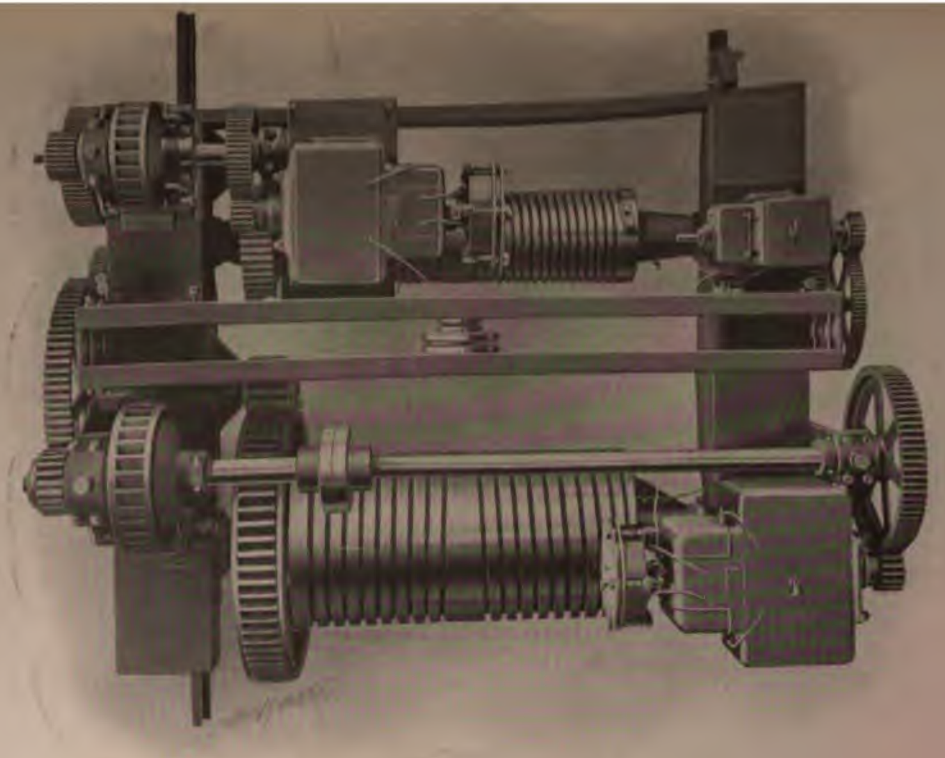
These machines are subject to extremes of temperature that have to be provided for in the design and arrangement of the parts. Being prime movers, controlling the operation of many machines, they must be certain to run during their period of work; hence design and adjustment must be positive, and when the latter cannot be made while running, it must be quickly and definitely accomplished when a stop is made. Simplicity of construction is essential, facilitating cheap and quick repairs. The design should be such that constant attention while running is avoided, the usual attention of the engineer being a safeguard rather than an implied factor of the original design. General rigidity and stiffness are important, also good balancing of the moving parts, and weight for absorption of vibration; otherwise under the constant daily run the machines will tear to pieces not only themselves but their foundations.

As far as external appearance goes in this and subsequent classes to be mentioned we are on a very different basis from that of machine tools. *General* mechanical symmetry of form is aimed at in the design, and the several smaller parts depend for their outline (aside from considerations of strength, which are, of course, always in order) upon the harmonious relation which they bear to the main and fundamental elements of the machine. Such machinery as air compressors, steam engines, pumps, and the like are viewed as a whole, and criticised, not detail by detail, as is the machine tool, but as to general effect of outline observed from some distance. To convey the desired effect to the eye the design must be bold and massive, connections simple and direct, and the smaller parts must not be so dwarfed in size as to appear like delicate ornaments instead of integral parts of the machine. The lines of connected parts must be continuous from one part to the other; and when interrupted by flanges, bosses, or lugs, the latter, which are merely incidental to the former must not be allowed to obscure wholly the main lines of the fundamental pieces.

It is attention to such points as these that marks the difference between well-designed motive-power machinery and that of the opposite character. Even though the little details of fillets and corners and surfaces may have their effect from a close point of view, the design will stand or fall in excellence on its bolder features, as noted above.

Structural Machinery. Examples:—Hoists, cranes, elevators, transfer tables, locomotives, cars, conveyors, cable-ways, etc., etc.

In the two preceding classes that have been noted, cast iron



TROLLEY OF 15 TONS CAPACITY.

The Case M'f'g Co.

the form of foundry castings enters as the principal material. ed is utilized for shafts, studs, pins, and keys. Also special rgings, malleable iron and steel castings enter as factors in the oduction of the machinery discussed. Foundry castings, however, compose the great body of the material used, and the chief oblems involved are those of the expert moulding of cast iron, d the handling and finishing of the same. For the operating rts, steel of [illegible] is used in highly finished form, expen- because of [illegible] and yet a necessity to the extent it is ed. Brass and [illegible] are used in the same way, generally in nnection with the bearings for the shafts.

Structural [illegible] the contrary, uses steel as the basis its construction [illegible] The fundamental structure is built up of ates, [illegible] castings, though [illegible] relatively [illegible] to the main structure [illegible]

[illegible]

in the form of foundry castings enters as the principal material. Steel is utilized for shafts, studs, pins, and keys. Also special forgings, malleable iron and steel castings enter as factors in the production of the machinery discussed. Foundry castings, however, compose the great body of the material used, and the chief problems involved are those of the expert moulding of cast iron, and the handling and finishing of the same. For the operating parts, steel of fine grade is used in highly finished form, expensive because of its fineness, and yet a necessity to the extent it is used. Brass and bronze are used in the same way, generally in connection with the bearings for the shafts.

Structural machinery, on the contrary, uses steel as the basis of its construction. The fundamental structure is built up of plates, channels, beams, and angles; castings, though numerous, are relatively small, being riveted or bolted to the main structure and controlled in their design by its requirements.

Steel is used in this manner partly because the exclusive use of castings is prohibited on account of the excessive weight, and therefore expense, and partly because castings could not be made which would possess the necessary toughness and strength. In many cases the size of the machinery is such that castings, even if they could be made, would not support their own weight. Moreover, machinery of this class is subjected to rough service, and yet must be practically infallible under all conditions, neither being uncertain in operation at critical moments nor entirely failing under an extraordinary load.

The design of structural machinery is tied up to conditions existing largely outside of the locality in which the machinery is built. The steel plates and structural shapes required, being products of the rolling mill, have to conform to the latter's standards. The rivets, bolts and other fastenings have to be in accordance with the established practice of the structural iron worker, in order to permit punching, shearing and bending machinery of regular form to be utilized. Shipment on standard railway cars has to be considered, the design often requiring to be modified to permit this and nevertheless insure positive and accurate assembling in the field.

Steel castings, both large and small, find ready application in this class of work; also steel forgings, requiring to be worked under a heavy hammer and in many cases by specially devised processes.

In structural design less of the actual process of manufacture is under the eye of the designer than in the former classes of machinery which have been considered, and hence more allowance has to be made for things not coming exactly right to the fraction of an inch. It would be bad design to plan any structural piece of work with the same closeness of detail permitted, and in fact required, in the case of machine tools, or even in the case of motive-power machinery. In planning structural work the idea must be carried out, of certainty of operation in spite of roughness of detail and variations of construction. This does not necessarily imply inaccuracy, or shiftless, loosely constructed machinery; on the contrary, quite the reverse. The locomotive, for example, is one of the most refined pieces of mechanism that exists today; and yet the methods applied to the construction of machine tools would prove a failure on the locomotive. The design of a car axle box has to be just right else it will heat and destroy itself; the same is true of the spindle of a fine engine lathe; and yet how rough the former is compared with the latter, and how unsuited either would be for use on the service of the other.

As a general rule structural machinery can be more closely proportioned to theoretically calculated size than can the preceding types. The rolled material of which it is made is of a uniform and homogeneous nature owing to its process of manufacture, hence its every fibre may be counted on to sustain its share of the total load imposed upon it. This is in sharp contrast to the case of cast iron, which is of such a porous and irregular structure that we have to use a large factor of safety to cover this inherent defect.

Steel castings of both small and large size (which are quite apt to be utilized in this class of machinery for parts that can with difficulty be made out of rolled material), if properly designed of uniform thickness, with all corners well filleted and with the channels for the flow of the molten metal direct and ample, are nearly as reliable as rolled steel. In parts subject to excessive vibration, shocks, and sudden wrenchings, as, for example, the side frames or the connecting rod of a locomotive, the forged and hammered material is practically a necessity. This is especially the case when the possible breakage of the part would cause serious consequences involving heavy loss of life and property.

From the several points of view as above considered, it can be readily appreciated that, while structural work is in one sense rough and unpolished, yet it requires, from an engineering standpoint, quite as much breadth of experience and judgment as any of the other types. The fine-tool designer, least of all, perhaps, requires book theory, but does require an extended machine-shop experience. The designer of motive-power machinery needs pure physical theory and shop experience of a large and broad scope. The structural designer is least of all concerned with refined and minute finishing processes, but utilizes his theory absolutely, even though roughly.

Mill and Plant Machinery. Examples:—Rolling mills, mining machinery, crushers, stamps, rock drills, coal cutters, the machinery of blast furnaces and steel mills, tube mills, etc., etc.

This machinery constitutes a class which in the roughness of its operation exceeds all others. Moreover, it is machinery which for the most part is in continuous operation—24 hours per day and 365 days in the year. Hence refinement, even such as might be permitted in the preceding class of Structural Machinery, would be fatal here. The conditions that surround plant machinery are unfavorable in the extreme to the life of any material or metal, and it is not possible to change these conditions or give more than partial protection to the operating parts. Hence the design of such machinery must proceed primarily on the assumption that abuse and neglect, grinding away of surfaces, chemical eating away of metal, flooding of parts with water gritty and corrosive, subjection to sudden bursts of flame and intense heat, etc., will in a relatively short time totally destroy, perhaps, the entire structure.

In view of the continuous nature of the working process, which must be kept up in spite of these almost insurmountable conditions, the problem in each case becomes one of expediency; and the designs and arrangement of machinery must be so worked out that operation, repair, construction, and installation can all go on simultaneously without stopping the continuous process, and with but a small degree of inconvenience to the operation of the plant.

This problem, difficult though it may seem, can be worked out successfully, as is evidenced by the great number of plants of the continuous character operating at high efficiency throughout the world. The engineering and designing skill required to accomplish this, is perhaps of the highest degree met with in modern practice, for in it is involved a working knowledge of the possibilities, if not the detailed designs of machinery included in all classes. And yet, as in the most elementary case of simple design that can be conceived, the result is accomplished in the same way, namely, by studying the conditions (analysis), developing an ideal application to those conditions (theory), and then reducing the ideal design to a practical basis (modification).

A Few Pointed Suggestions on Original Design. Original design deals with the development of original mechanical ideas. The prime requisite for the development of an idea is to understand thoroughly the idea in the rough. See distinctly the mark aimed at, and never lose sight of it. If a method of reaching it is already outlined, understand that also thoroughly and the principles involved. It is impossible to go ahead blindly and hope to come out right. No good machine was ever built that does not stand for hours of concentrated thought on the part of its designer. Good machines never *happen*, they always *grow*.

Just as soon as the object to be accomplished is clearly understood, begin to produce some visible work on the problem. Sketch something. Get some ideas on paper. Ideas on paper suggest other ideas. If the problem, for example, is one of lathe design, sketch a rectangle, and call it the headstock; another rectangle, and call it the footstock; a couple of scratches for the centers; some steps for the cone pulley; three or four lines for the bed; and as many more for the supports. There is now something on paper to look at; the design is begun.

It is much better to stare at this sketch, than into blank space trying to imagine the finished design. No matter how rough the sketch may be, a short study of it will develop some limiting conditions that before were not apparent. Guess at a few rough dimensions; put them on the sketch; develop another view—a plan or a side elevation—all still in the roughest style, without any regard to finished detail. Information will be growing all the while, and the problem will be opening up. At this stage it is probable that the sketch can easily be seen to be wrong in many respects. Perhaps the arrangement will not do at all.

This is a good sign. It shows that the design is progressing. It is a valuable thing to know that certain plans *cannot* be followed. Do not rub out part of the sketch already made and try to remedy it. Begin again. Make another sketch. Sketch paper is cheap. By and by it may prove to be very desirable to have that first rough outline available for comparison; or it may be that some of its ideas can be applied on other sketches. The second sketch may "show up" little or no better than the first. Make another, and another, and another, until the subject is thoroughly digested. It is wonderful how helpful it is to have some marks on paper relative to a design, even though they be of the utmost crudeness. They save imaginative power tremendously; and, even with them, all available powers of imagination will be needed before the design is perfected.

A careful comparison of one's sketches, rejecting here, and approving there, will, little by little, bring about a definite opinion, and the scale drawing can be begun.

As in the case of the first sketch, so in the case of the first scale drawing, get some lines on paper as quickly as possible. Draw something, even if it is nothing more than a straight horizontal line. Do not stare at blank paper for an hour trying to imagine how the tenth or eleventh line is going to be drawn in relation to the first line. Do not worry about the later lines until it is time for them Draw the first line at once; and, when the second line is drawn, if the first line proves to be wrong, make it right. As in the rough sketch, that first horizontal line is an immense relief from the great waste of blank paper of a fresh sheet. It is something to look at. It is the beginning of a detailed design. If it happens not to be the absolutely correct foundation to build upon, it at least is something to tear down. The main purpose of these preliminary drawings is to keep the mind active on the problem; and advance toward the final accomplishment of the design is often made quite as rapidly by discovering what to tear down as by consistently building up.

When a detail draftsman who has been used to having all his work laid out for him by an expert designer attempts to take up original work for himself, he encounters the drawing of that first line in a way he never did before. He is apt to worry for some time over the possible or impossible results of drawing that first line. If he continue this, he will be sure to fail. The second line is much easier to draw than the first, and the third than the second; and the next hundred will follow on in comparatively smooth sequence, all because of bold action on the first few lines.

And yet, just as the design appears to be progressing smoothly, and the advanced progress of the drawing seems cause for congratulation, careful consideration may disclose a "snag" not previously known to exist in the problem. Further study pursued along the line of this new discovery may show that the whole layout thus far has been radically wrong, and that a fresh start will have to be made. At such a time the young designer is apt to feel that his labor has all been thrown away, and he becomes discouraged. There is, however, no cause for discouragement. Machine Design might almost be defined to be the "successful elimination of snags." It takes some ability to discover an obstacle of this sort; to know a "snag" when an opportunity to see it is given. It takes a good designer to eliminate such a difficulty after it has been found. If there were no "snags" it would not require great ability to design machines. Many machines fail because in them there are a lot of undiscovered "snags." Others fail because the "snags," although discovered, were not eliminated by careful design.

Do not be afraid to make a lot of "first" drawings. It is just as important to digest the design thoroughly by means of scale drawings, as it was to digest it originally by means of the rough sketches. An attempt to make the first drawing of an original design absolutely right would, it is safe to say, produce a poor design, one that could be much improved by further trial. Let the drawings multiply, one after another, until the final one is reached, in which the perfection of detail will eliminate all the bad points of the preceding drafts and incorporate good ones of its own based on the study of the others.

And yet it is often true that the first design laid out, even after many others have been developed, may be found to possess features that render a return to it desirable. This is why it is always better to produce a collection of designs than to attempt to rub out and work over the first one. The best designers usually have a great number of sketches showing how to accomplish a single result. Likewise, they also have a series of layouts to scale, showing in detailed form the development of their various ideas. This is because, without a careful consideration of many methods, they themselves feel incompetent to judge of the best design possible for accomplishing a given result.

Sketches and original designs should always be dated and signed. Different designers may be working on the same problem, and priority of design will never be allowed except upon signed and witnessed papers. It is embarrassing to find, after months and perhaps years have passed since an original drawing was made, that one's rights have been preëmpted merely because there was no date or signature to define them.

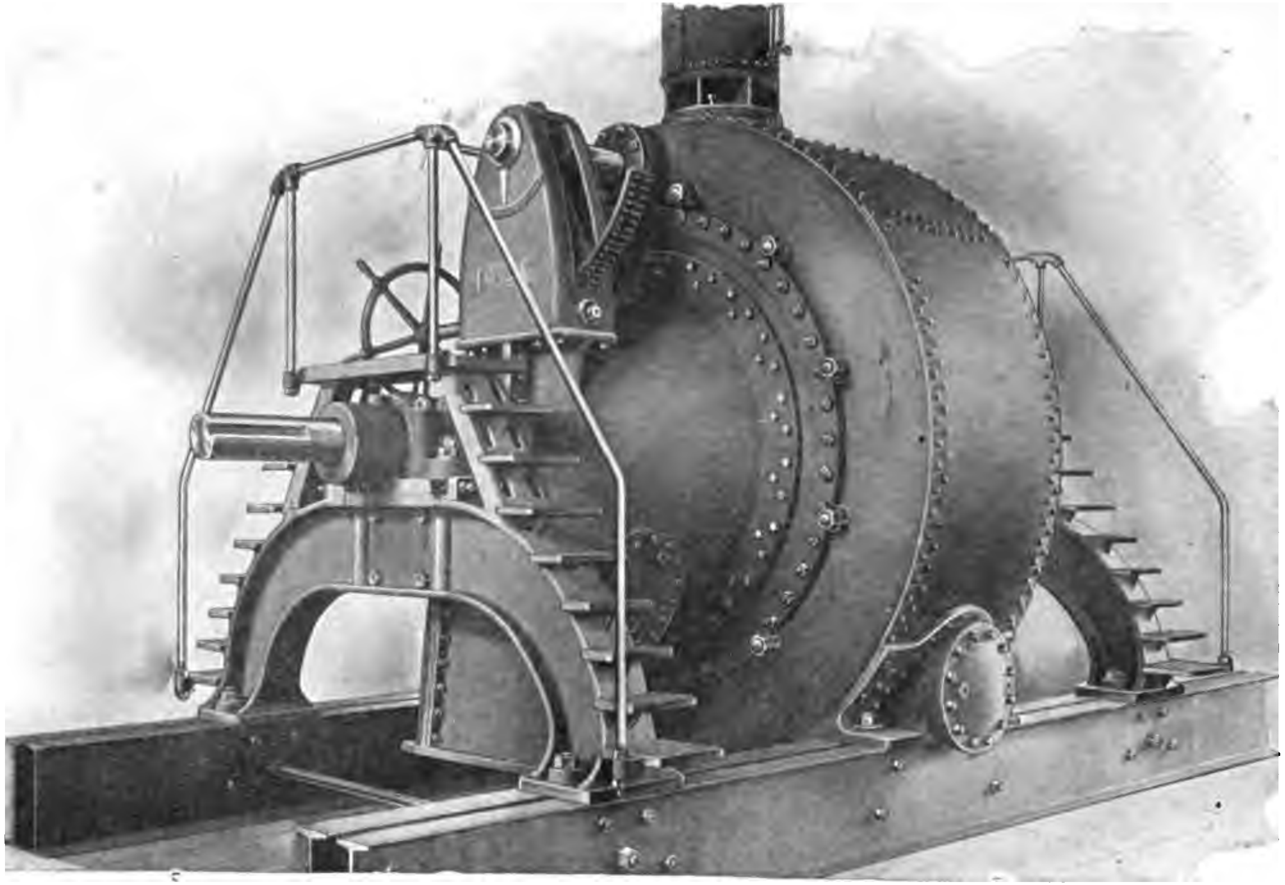
In redesigning or modifying an existing machine, never make a change merely for the sake of doing so. Give the good points of the machine a chance, and devote attention in the new design to correcting the bad points. It is in bad taste, if it be not actually childish, to "look wise and suggest a change" in details which happen to have been designed by another party, but which, nevertheless, are by common engineering judgment pronounced good for the special work intended. This element of unfair and selfish criticism has more than a moral bearing. When it is carried into the superintendence of designing work, it extinguishes the personality of the subordinate draftsman; his efficiency as an original thinker is lowered; and narrow designs are produced.

"The best way for a subordinate to dispose of what appears to be a poor suggestion from a superior, is to work it out to the best degree possible." If it turns out to be good the credit of working it out belongs to the man who did it. If it is actually bad, a careful working out will usually develop the fact beyond dispute, and save unprofitable argument. For the success or failure of a machine there is only one argument better than the detail drawings, and that is the machine itself in operation.

Detail drawings, however, are infinitely better prosecutors or defendants than a multitude of wordy counsel.

Summary. The above classification of machinery might be subdivided and extended indefinitely, and on the broad basis on which it is given it doubtless does not cover the entire field. As an illustration, however, not only of types of machinery, but of methods of design and study, it is hoped that it may be of assistance in giving a start to the student of machine design, in whatever class his interests may happen to lie.

It is the general principles of the art which it is important to master. It is not the designing of a locomotive, or a stationary steam engine, or a crane, or an engine lathe, or a rolling mill, which should be sought to be learned, but the designing of *anything* that may confront us. Specializing is sure to come to the designer in the course of his experience, and when it does he merely fits to the particular specialty the principles he knows for all, and practically develops them along that individual line.



HIGH DUTY SAMPSON TURBINE. NIAGARA DESIGN.

James Leffel and Co.

MACHINE DESIGN.

PART II.

Introduction. In Part I is illustrated a definite and systematic method of attacking the design of a *machine as a whole*. In Part II the same plan is followed with regard to the detail of its *component parts*, the machine elements which are chosen as illustrations of the method, being the simplest and most familiar forms in common use.

As before, the student must strive to grasp and absorb the *method* of design rather than any specific and established form of a machine part. Part II is not a compendium of design, does not attempt to be complete or exhaustive in any of its chapters, but is condensed and simplified in order to lead the student into systematic mechanical thinking and logical and definite action. Each chapter is intended to stimulate to further and more exhaustive study along lines broader than, and under conditions different from those that can be specified in a general discussion. But no matter how deeply investigation may be carried, or how specialized the study may become, the student must realize that his path of action in any case whatsoever must lie along the lines of *Analysis, Theory*, and *Practical Modification* systematically applied.

BELTS.

NOTATION- The following notation is used throughout the chapter on Belts:

A = Sectional area of belt (square inches) $= bh$.
b = Width of belt (inches).
F = Force of friction at pulley rim (lbs.).
h = Thickness of belt (inches)
μ = Coefficient of friction.
N = Number of revolutions of pulley per minute.
n = Fraction of circumference of pulley embraced by belt.
P = Driving force at pulley rim (lbs.) $= F$.

R = Radius of pulley (feet).
r = Radius of pulley (inches).
T = Initial tension (lbs.).
T_t = Total tension on tight side (lbs.).
T_s = Total tension on slack side (lbs.).
t = Working tension of belt (lbs. per square inch).
V = Velocity of belt (feet per minute).
w = Weight of belt per cubic inch (lbs.).
z = Factor due to centrifugal force.

ANALYSIS. When a belt is stretched over a pair of pulleys, is cut off at the proper length, and is laced together into an endless band, it is evident that as long as the belt is at rest there is a nearly uniform tension in it throughout its length, due to the tightness with which the lacing is drawn up. If the distance between the pulleys is considerable, the weight of the belt itself as it hangs between the pulleys will produce a slightly greater tension next to the pulleys than exists in the middle of the span. This increase of tension due to the weight of the belt would make but little difference in the unit-stress in the material of which the belt is made; hence it may safely be assumed that the tension in the belt when at rest is uniform throughout its entire length.

When we start to transmit power through the belt by turning one of the pulleys, thereby driving the other pulley the condition of stress in the belt is at once materially changed. As the belt is a flexible member, we can transmit only a pull to the other pulley, thereby turning it around, the push which is at the same time given to the other side of the belt merely acting to make the belt sag or become slack. Hence the immediate effect of starting motion in a belt is to change the condition of equal tension throughout its length, to that of unequal tension in the two sides. The driving side is tight, while the other is loose, the former having gained as much tension as the latter has lost, and the sum of the two being practically equal to the sum of the tensions in the two sides of the belt when at rest. This is not strictly true, as will be shown later; but it is sufficiently accurate to form a good basis for the practical design, at least of slow-speed belts.

This condition of tight and slack sides is made possible by the fact that the belt, in being wrapped around the pulleys under tension, has friction on their surfaces. Thus, we can pull hard on one side without slipping the belt around the pulleys, but could not do this if the pulleys were perfectly smooth or frictionless, for in that case the slightest pull on one side would slip the belt around the pulleys. In fact, it would be impossible to produce any pull by means of the driving pulley, for the pulley would merely slip around inside the belt.

The amount of pull we can apply to the belt is therefore limited by the tension at which the belt slips around the pulley. Moreover, since the force of friction between the belt and pulley is dependent upon the normal force with which the belt is pressed against the pulley, and the coefficient of friction between the two, it is evident that the tighter the belt is laced up, and the rougher the surfaces of the pulley and belt, the greater is the force that can be transmitted through the belt. This leads to the conclusion that it would be possible to transmit any amount of power through any belt however small, if the belt were only laced up tight enough.

This conclusion is literally true; but the important fact now comes in, that the strength of the material of which the belt is made is limited, and while theoretically we might be able to accomplish the above, it would be impossible to do so in practice, for at a certain point the belt would break under the strain. Other practical considerations also come in, which fix this limit of power transmission at a point far below the breaking strength of the material.

The complete analysis is not quite as simple as the above, especially for high-speed belts. When the driving side of the belt becomes tight, it stretches and grows longer; and at the same time the other side of the belt becomes slack and grows shorter. But it is not true that the increase in the one side is the same as the decrease in the other, and this fact produces the condition that the sum of the tensions in motion is not quite the same as the sum of the tensions at rest.

Again, when the belt, as it passes around the pulley, changes its straight-line direction to circular motion, each particle of the belt—like a body whirling at the end of a cord about a center of rotation—tends by centrifugal force to fly away from the surface of the pulley, thereby decreasing the normal pressure, and hence the friction. This centrifugal force also changes somewhat the tensions in the belt between the pulleys. As the centrifugal force increases in proportion to the square of the linear velocity, it is evident that the effect is greater at high speeds than at moderate or low speeds.

A further circumstance that affects the driving power of a belt is the stiffness of the leather or other material of which the belt is made. As it passes around the pulley, the belt is bent to conform to the circumference of the pulley, and is again straightened out as it leaves the pulley. Hence the theoretically perfect action is modified somewhat according to the sharpness of the bending and the thickness or flexibility of the belt; in other words, a small pulley carrying a thick belt would be the worst case for successful calculation on a theoretical basis.

THEORY. The condition of the tight and loose sides of a belt transmitting power, is similar to that of the weighted strap and fixed pulley shown in Fig. 17. If motion is desired of the strap around the pulley, it is necessary to make the weight W_2 of such a magnitude that it will overcome not only the weight W_1, but also the friction between the strap and the pulley. The strap tension T_n is, of course, equal to W_2, and T_o to W_1. The equation showing the balance of forces for the condition when motion is about to occur, is:

$$T_n - T_o = F = P \text{ (driving force).} \qquad (5)$$

If the pulley be free to turn on its axis, instead of being fixed as in Fig. 17, the strap by its friction on the pulley will turn the pulley, and the force of friction F becomes the driving force for the pulley as noted in equation 5 above.

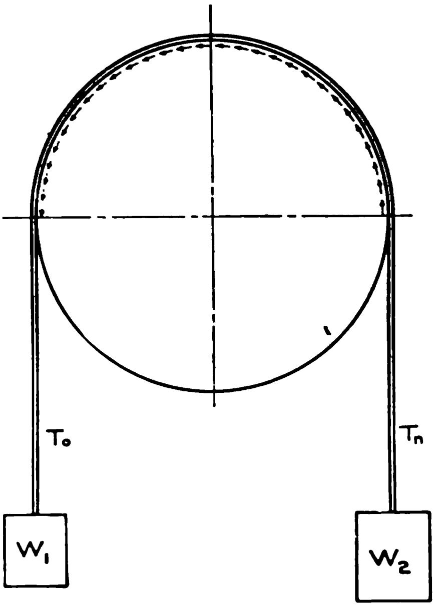


Fig. 17.

In Fig. 18, let us suppose that W is a weight representing the resistance to be overcome. The tensions T_n and T_o, equal at first owing to stretching the belt tightly over the pulleys at rest, change when an attempt is made to raise the weight by turning the larger pulley; and just as the weight leaves the floor, the equality of moments about the axis of the driven pulley gives the following equation:

$$(T_n - T_o) r = F \times r = P \times r = W \times r_1. \qquad (6)$$

This equality of moments remains as long as the motion of the weight is uniform, and represents closely the conditions under which belt pulleys work.

Although we know from the above what the *difference* of the belt tensions is, and what this difference will do when applied to the surface of a given pulley, we do not yet know what either T_n or T_o actually is; and until we do know, we cannot correctly proportion the belt. Hence we must find another relation between T_n and T_o which we can combine with equations 5 and 6. This relation is deduced by a process of higher mathematics, which results as follows:

$$\text{Common logarithm } \frac{T_n}{T_o} = 2.729\,\mu\,(1 - z)n. \qquad (7)$$

Treating equations 5 and 7 as simultaneous, values of both T_n and T_o can be found by the regular algebraic solution. As T_n is the larger, the actual area of belt to provide the necessary strength must be made to depend upon it.

The factor z in equation 7 depends upon the centrifugal force developed by the weight of the belt passing around the pulley. Its value, found from mechanics, is:

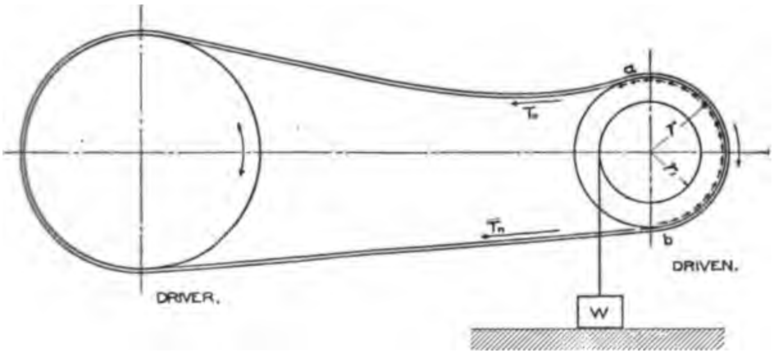


Fig. 18.

$$z = \frac{w \times V^2}{9{,}660 \times t}.$$

Having found the maximum pull on the belt, it now remains to write the equation:

External force = Internal resistance;

or,
$$T_n = b \times h \times t. \qquad (8)$$

Usually the most convenient way to handle this equation is to assume h and t, and then solve for b.

Summing up the theoretical treatment of belt design, we simply combine equations 5, 6, 7, and 8, and solve for the quantity desired. Discussion of the constants involved in these equations, and of the practical factors controlling them, is given in the following:

PRACTICAL MODIFICATION. The force of friction F, which is the same as driving force P, depends on:

Coefficient of friction (μ) between belt and pulley;
Tightness of the belt;
Centrifugal force of the belt;
Angle of contact of belt with pulley.

The coefficient of friction (μ), according to experiments and observed operation of belts transmitting power, varies from .15 to .56 for leather on cast iron. An average value consistent with a reasonable amount of slip, the belt being in good running order, is .30. If the belt is oily, or likely to become so in use, a lower value should be taken.

The tighter the belt is drawn up, the greater is the pressure against the pulley, and hence the greater is the force of friction. But if we pull the belt up too tightly, when we begin to drive, T_n becomes too great, and the belt breaks or is under such stress that it wears out quickly. Moreover, the great side pressure on the bearings carrying the shaft produces excessive friction, and the drive is inefficient. This is why a narrow belt driven at high speed is more efficient than a wide belt at slow speed, for we cannot pull up the former as tightly as the latter without overstraining it, and yet it is possible to get the required power out of the narrow belt by running it at high speed.

The centrifugal force is of small importance for low speeds, say of 3,000 feet per minute and less; and it therefore may usually be neglected. The factor z then becomes zero in the expression $1 - z$ in equation 7, and the second member of the equation stands simply $2.729 \times \mu \times n$.

The angle of contact of belt with pulley is important, as a large value gives a great difference between T_n and T_o; and it is desirable to make this difference as great as possible, because thereby the driving force is increased. The loose side of a horizontal belt should always be above, as then the natural sag of the loose

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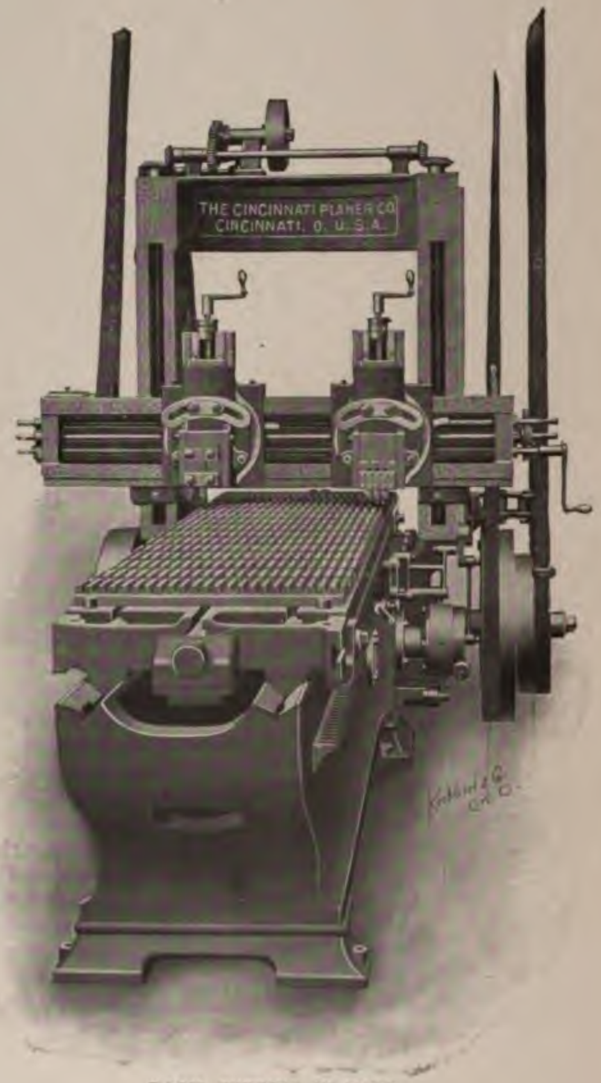
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RACK CUTTING PLANER.

side due to its slackness tends to increase the angle of contact with the pulley, while the tightening up of the lower side acts against its sag to make the loss of wrap as little as possible. Vertical belts which have the driving pulley uppermost, utilize the weight of the belt to increase the pressure against the surface of the pulley, slightly increasing its capacity for driving. The angle of contact may be artificially increased by a tightening pulley which presses the belt further around the pulley than it would naturally lie. It adds however, the friction of its own bearing, and impairs the efficiency of the drive. For ordinary horizontal belts, the angle of contact is but little more than 180°, and the value of n in equation 7 may be safely assumed at $\frac{1}{2}$ unless the pulleys are of relatively great difference of diameter and very close together.

Strength of Leather Belting. The breaking tensile strength of leather belting varies from 3,000 to 5,000 pounds per square inch. Joints are made by lacing, by metal fasteners, or by cementing. The strength of a laced joint may be about $\frac{7}{10}$, of a metal-fastened joint, about $\frac{1}{2}$, and of a cemented joint, about equal to the full strength of the belt cross-sectional area. The proper working strength of belting depends on the use to which the belt is put. A continuously running belt should have a low tension in order to have long life and a minimum loss of time for repairs. For double leather belting it has been shown that a working tension of 240 pounds per square inch of sectional area gives an annual cost — for repairs, maintenance, and renewals — of 14 per cent of first cost. At 400 pounds working tension, the annual expense becomes 37 per cent of first cost. These results apply to belts running continuously; larger values may be used where the full load comes on but a short time, as in the case of dynamos.

Good average values for working tensions of leather belts are:

Cemented joints,	400	pounds per square inch.
Laced joints,	300	" " " "
Metal joints,	250	" " " "

Horse-Power Transmitted by Belting. If P is the driving force in pounds at the rim of the pulley, and V is the velocity of the belt in feet per minute, the theoretical horse-power transmitted is evidently :

$$\text{H. P.} = \frac{P \times V}{33{,}000}\,. \qquad (9)$$

It is evident from the above that the horse-power of a belt depends upon two things, the driving force P and the velocity V. If either of these factors is increased, the horse-power is increased. Increasing P means a tight belt. Hence a tight belt and high speed together give maximum horse-power. But a tight belt means more side strain on shaft and journal. Therefore, from the standpoint of efficiency, *use a narrow belt under low tension at as high a speed as possible.*

Empirical rules for horse-power of belting, if used with judgment, give safe results when applied to very general cases. A common rule used by American engineers is:

$$\text{H. P.} = \frac{b \times V}{1{,}000}\,. \qquad (10)$$

For a double belt, assuming double strength, this becomes:

$$\text{H. P.} = \frac{b \times V}{500}\,. \qquad (11)$$

With large pulleys and moderate velocities, this may hold good. With small pulleys and high velocities, however, the uncertain stresses induced by the bending of the fibers of the belt around the pulley, and the relatively great loss due to centrifugal force, modify this relation and a safer value for a double belt of the ordinary kind is:

$$\text{H. P.} = \frac{b \times V}{540}\,; \qquad (12)$$

or, still safer,

$$\text{H. P.} = \frac{b \times V}{700}\,. \qquad (13)$$

If we compare the theoretical value of equation 9 with the empirical value of equation 10 by putting them equal to each other, thus:

$$\text{H. P.} = \frac{P \times V}{33{,}000} = \frac{b \times V}{1{,}000}\,.$$

and solve for P, we get :

$$P = 33b. \qquad (14)$$

This develops the fact that the empirical rule of equation 10 assumes a driving force of 33 pounds per inch of width of single belt.

Another way of expressing equation 10 is: A single belt will transmit one horse-power for every inch of width at a belt speed of 1,000 feet per minute.

Speed of Belting. The most economical speed is somewhere between 4,000 and 5,000 feet per minute. Above these values the life of the belt is shortened; also "flapping," "chasing," and centrifugal force cause considerable loss of power. The limit of speed with cast-iron pulleys is fixed at the safe limit for bursting of the rim, which may be taken at one mile per minute.

Material of Belting. Oak-tanned leather, made from the part of the hide which covers the back of the ox, gives the best results for leather belting. The thickness of the leather varies from .18 to .25 inch. It weighs from .03 to .04 pound per cubic inch. The average thickness of double leather belts may be taken as .33 inch, although a variation in thickness from $\frac{1}{4}$ inch to $\frac{7}{16}$ inch is not uncommon. Double leather belts may be ordered light, medium, or heavy.

In a single-thickness belt the grain or hair side should be next to the pulley, for the flesh side is the stronger and is therefore better able to resist the tensile stress due to bending set up where the belt makes and leaves contact with the pulley face. Double leather belts are made by cementing the flesh sides of two thicknesses of belt together, leaving the grain side exposed to surface wear.

Raw hide and semi-raw hide belts have a slightly higher coefficient of friction than ordinary tanned belts. They are useful in damp places. The strength of these belts is about one and one-half times that of tanned leather.

Cotton, cotton-leather, rubber, and leather link belting are some of the forms on the market, each of which is especially adapted to certain uses. For their weights and their tensile and working strengths consult the manufacturers' catalogues.

A prominent manufacturer's practice in regard to the sizes of leather belting will be found useful for comparison, and is indicated in the table on page 12.

Initial Tension in Belt. On the assumption that the sum of the tensions is unchanged, whether the belt be at rest or driving, we should have the following relation :

$$T_n + T_o = 2T;$$

whence,

$$T = \frac{T_n + T_o}{2}. \qquad (15)$$

This is not strictly true, however, as is stated in the "Analysis" of "Belts." It has been found that in a horizontal belt working at about 400 lbs. tension per square inch on the tight side, and having 2 per cent slip on cast-iron pulleys (*i. e.*, the surface of the driven pulley moving 2 per cent slower than that of the driver), the increase of the sum of the tensions when in motion over the sum of the tensions at rest, may be taken at about $\frac{1}{3}$ the value of the tensions at rest. Expressing this in the form of an equation

Sizes of Leather Belting.

WIDTH.	THICKNESS.	
	Single.	Double.
1 inch.	$\frac{3}{32}$ inch.	$\frac{5}{16}$ inch.
2 "	$\frac{3}{16}$ "	$\frac{5}{16}$ "
3 "	$\frac{7}{32}$ "	$\frac{3}{8}$ "
4 "	$\frac{7}{32}$ "	$\frac{3}{8}$ "
5 "	$\frac{7}{32}$ "	$\frac{3}{8}$ "
6 "	$\frac{7}{32}$ "	$\frac{3}{8}$ "
10 "	$\frac{5}{16}$ "	$\frac{3}{8}$ "
12 "	....	$\frac{3}{8}$ "
14 "	....	$\frac{13}{32}$ "
20 "	....	$\frac{7}{16}$ "

$$T_n + T_o = \frac{4}{3}(2T) = \frac{8T}{3}.$$

$$T = \frac{3}{8}(T_n + T_o). \qquad (16)$$

The value of T thus found would be the pounds initial tension to which the belt should be pulled up when being laced, in order to produce T_n and T_0 when driving.

This value is not of very great practical importance, as the proper tightness of belt is usually secured by trial, by tightening pulleys, by pulley adjustment (as in motor drives), or by shortening the belt from time to time as needed. It is worth noting, however, that for the most economical life of the belt it would be very desirable in every case to weigh the tension by a spring balance when giving the belt its initial tension. This, however, is not always easy or even feasible; hence it is a refinement with which good practice usually dispenses, except in the case of large and heavy belts.

PROBLEMS ON BELTS.

1. Determine the belt tensions in a laced belt transmitting 50 horse-power at a velocity of 3,500 feet per minute. Suppose that the arc of contact is 180°; weight of belt = .035 pound per cub. in.; and coefficient of friction 25 per cent.

2. What is the width of above belt if it is $\frac{3}{16}$ inch in thickness?

3. What initial tension must be placed on above belt?

4. The main drive pulley of a 120-horse-power water wheel is 6 feet in diameter. A cemented leather belt is to connect the main pulley to a 3-foot pulley on the line shafting in a mill. The horizontal distance between centers of shafting is 24 feet; coefficient of friction, 30 per cent; revolutions per minute of line shafting, 180. Design the belt for this drive.

5. An 8-inch double belt $\frac{3}{8}$ inch thick connects 2 pulleys of 30-inch and 20-inch diameter respectively. The horizontal distance between the centers is 12.5 feet. The coefficient of friction is 0.3, and the weight of belt per cubic inch is 0.035 pound. Working tension, 300 pounds per square inch. Speed of belt 5,000 feet per minute. Lower face of 30-inch pulley is the driving face. Required the H. P. which may be transmitted (theoretically).

6. Compare the theoretical horse-power in problem 5 with that obtained by the use of empirical formula.

PULLEYS.

NOTATION—The following notation is used throughout the chapter on Pulleys:

A = Area of rim (sq. in.).
a = " " arm (" ").
b = Center of pulley to center of belt (inches; practically equal to R).
C_1 = Total centrifugal force of rim (lbs.).
c = Distance from neutral axis to outer fiber (inches).
D = Diameter of pulley (inches).
D_1 = " " hub (").
d_1 = " " bolt at root of thread (inches).
d = Diameter of bolt holes (inches).
g = Acceleration due to gravity (ft. per sec.).
h = Width of arm at any section (inches).
I = Moment of inertia.
L = Length of arm, center of belt to hub (inches).
L_1 = Length of rim flange of split pulley (inches).
l = Length of hub (inches).
N = Number of arms.
n = " " rim bolts, each side.
P = Driving force of belt (lbs.).
P_1 = Force at circumference of shaft (lbs.).
P_2 = Force at circumference of hub (lbs.).
p = Stress in rim due to centrifugal force (lbs. per sq. in.).
R = Radius of pulley (inches).
S = Fiber stress (lbs. per sq. in.).
s = Fiber stress in flange (lbs. per sq. in.).
T = Thickness of web (inches).
t = " " rim (").
t_2 " " " bolt flange (inches).
T_n = Tension of belt on tight side (lbs.).
T_0 = " " " " loose " (").
v = Velocity of rim (ft. per sec.).
w = Weight of material (lbs. per cub. in.).

ANALYSIS. If a flexible band be wrapped *completely* about a pulley, and a heavy stress be put upon each end of the band, the rim of the pulley will tend to collapse just like a boiler tube with steam pressure on the outside of it. A compressive stress is induced which is very nearly evenly distributed over the cross-section of the rim, except at points where the arms are connected thereto. At these points the arms, acting like rigid posts, take this compressive stress. Now, a pulley never has a belt wrapped *completely* round it, the fraction of the circumference embraced by the belt being usually about $\frac{1}{2}$, and seldom, even with a tightener pulley, reaching $\frac{3}{4}$. Assuming the wrap to be $\frac{1}{2}$ the circumference, and that all the side pull of the belt comes on the rim, none being transmitted through the arms to the hub, we then have one-half of the rim pressed hard against the other half by a force equal to the resultant of the belt tensions, which, in this case, would be the sum of them. Dividing the pulley by a plane through its center and perpendicular to the belt, the cross-section of the rim cut by this plane has to take this compressive stress.

This analysis is satisfactory from an ideal standpoint only, for the intensity of stress due to the direct pull of the belt, with the usual practical proportions of rim, would be very small. Moreover, the element of speed has not been considered.

When the pulley is under speed, a set of conditions which plicates matters is introduced. The centrifugal force due to weight of the rim and arms is no longer negligible, but has important influence upon the design and material used. This ntrifugal force acts against the effect of the belt wrap, tending o reduce the compressive stress, or, overcoming the latter entirely, ets up a tensional stress both in the rim and in the arms. It also tends to distort the rim from a true circle by bowing out the rim between the arms, thus producing a bending moment in the rim, maximum at the points where the rim joins each arm.

It can readily be imagined that the analysis in detail of these various stresses in the rim acting in conjunction with each other is quite complicated — far too much so in fact, to be introduced here. As in most cases of such design, however, one controlling influence can be separated out from the others, and the design based thereon with sufficient margin of strength to satisfy the more obscure conditions. This is rational treatment, and the "theory" will be studied accordingly.

The rim, being fastened to the ends of the arms, tends, when driving, to be sheared off, the resisting area being the areas of the cross-sections of the arms at their point of joining the rim. The force that produces this shearing tendency is the driving force of the belt, or the difference between the tensions of the tight and loose sides.

Again, at the point of connection of the arms to the hub, a shearing action takes place, so that, if this shearing tendency were carried to rupture, the hub would literally be torn out of the arms. Now, viewing the arms as beams loaded at the end with the driving force of the belt, and fixed at the hub, a heavy bending stress is set up, which is maximum at the point of connection to the hub. If the rim were stiff enough to distribute this driving force equally between the arms, each arm would take its proportional share of the load. The rim, however, is quite thin and flexible; and it is not safe to assume this perfect distribution. It is usual to consider that one-half the whole number of arms take the full driving force.

THEORY—Pulley Rim. Evidently it is practically impossible to make so thin a rim that it will collapse under the pull of a belt. As far as the *theory* of the rim is concerned, its proportion probably depends more upon the calculation for centrifugal force than upon anything else.

In order to separate this action from that of any other forces, let us suppose that the rim is entirely free from the arms and hub, and is rotating about its center. Every particle, by centrifugal force, tends to fly radially outward from the center. This condition is represented in Fig. 19. The tendency with which one-half of the rim tends to fly apart from the other is indicated by the force C_1; and the relation between C_1 and the small radial force c for each unit-length of rim can readily be found from the principles of mechanics. The case is exactly like that of a boiler or a thin pipe subjected to uniform internal pressure, which, if carried to rupture, would split the rim along a longitudinal seam.

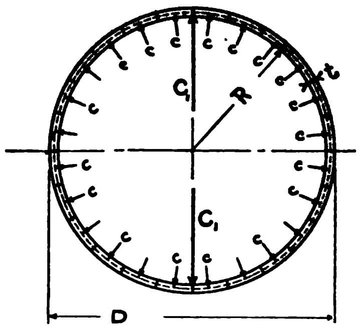


Fig. 19.

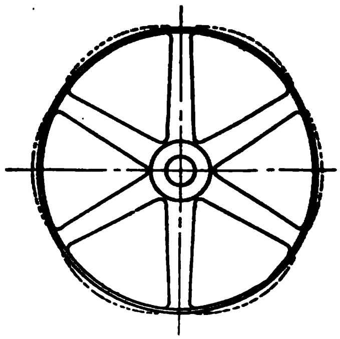


Fig. 20.

The tensile stress thus induced per square inch can be found by simple mechanics to be:

$$p = \frac{12wv^2}{g}; \qquad (17)$$

or, since $w = 0.26$ pound, and $g = 32.2$ feet per second,

$$p = 0.097\,v^2 \quad \left(\text{say } \frac{v^2}{10}\right); \qquad (18)$$

and, if p be taken equal to 1,000 pounds per square inch, which is as high as it is safe to work cast iron in this place,

$$v = 100 \text{ feet per second.} \qquad (19)$$

This shows the curious fact that the intensity of stress in the rim is directly proportional to the square of the linear velocity, and wholly independent of the area of cross-section. It is also to be noted that 100 feet per second is about the limit of speed for cast-iron pulleys to be safe against bursting.

If we wish to consider theoretically the rim together with the arms as actually connected to it, we get a much more complicated relation. This condition is shown in Fig. 20, where the rim, expanding more than the arms, bulges out between them. This makes the rim act something like a continuous beam uniformly loaded; but even then the resulting stress is not clearly defined on account of the variable stretch in the arms. Investigation on this basis is not needed further than to note that it is theoretically better, in the case of a split pulley, to make the joint close to the arms, rather than in the middle of a span.

Pulley Arms. The centrifugal force developed by the rim and arms tends to pull the arms from the hub. On the belt side, this is balanced to some extent by the belt wrap, which tends to compress the arm and relieve the tension. On the side away from the belt, the centrifugal action has full play, but the arm is usually of such cross-section that the intensity of this stress is very low. It may safely be neglected.

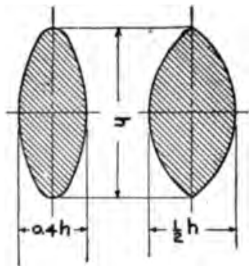


Fig. 21.

The rim being very thin in most cases, its distributing effect cannot be depended on, hence the driving force of the belt may be taken entirely by the arms immediately under the portion of the belt in contact with the pulley face. For a wrap of 180° this means that only one-half of the pulley arms can be considered as effective in transmitting the turning effort to the hub. Each of these arms is a lever fixed at one end to the hub and loaded at the other. A lever of this description is called a "cantilever" beam, its maximum moment existing at its fixed end. The load that each of these beams may be subjected to is $\frac{P}{\frac{N}{2}}$, and therefore the maximum external moment at the hub is $\frac{2PL}{N}$. From mechanics we know that the internal moment of resistance of any beam section is $\frac{SI}{c}$, and that equilibrium of the beam can be satisfied only when the external moment is equal to the internal moment of resistance of the beam section. Equating these two, we have:

$$\frac{2PL}{N} = \frac{SI}{c}. \qquad (20)$$

The arms of a pulley are usually of the elliptical or segmental cross-section, and may be of the proportions shown in Fig. 21. For either of these sections the fraction $\frac{I}{c}$ is approximately equal to $0.0393h^3$. For convenience (the error caused being on the safe side), L may be taken as equal to the full radius of the pulley R, whence

$$\frac{2PR}{N} = \frac{2(T_n - T_o)R}{N} = 0.0393Sh^3, \qquad (21)$$

in which S may be from 2,000 to 2,250 for cast iron

Taking moments about the center of the pulley, and solving for P_2, the force acting at the circumference of the hub, we have:

$$\frac{2PR}{N} = \frac{P_2D_1}{2};$$

or

$$P_2 = \frac{4PR}{ND_1} \qquad (22)$$

The area of an elliptical section is π times the product of the half axes. With the proportions of Fig. 21, this becomes:

$$a = \pi \times 0.2h \times 0.5h = \frac{\pi h^2}{10} \qquad (23)$$

Equating the external force to the internal shearing resistance, we have:

$$\frac{4PR}{ND_1} = \frac{\pi h^2 S_s}{10}$$

or,

$$S_s = \frac{40PR}{D_1N\pi h^2}, \qquad (24)$$

in which the shearing stress S_s may run from 1,500 to 1,800 for cast iron.

Although both bending and shearing stresses as calculated above exist at the base of the arms, the bending is, in practically every case, the controlling factor in the design of the arms. An arm-section large enough to resist bending would have a very low intensity of shear.

If the number of arms be increased indefinitely, we come to a continuous arm or web, in which the bending action is eliminated. It may still shear off at the hub, where the area of metal is the least, at minimum circumference. In this case the area under shearing stress is $\pi D_1 T$; and the force at the circumference of the hub, is

$$\frac{PR}{\frac{D_1}{2}} = \frac{2PR}{D_1}$$

Equating external force to internal shearing resistance, we have:

$$\frac{2PR}{D_1} = \pi D_1 T S_s;$$

$$\text{or,}\quad S_s = \frac{2PR}{\pi D_1^2 T}. \qquad (25)$$

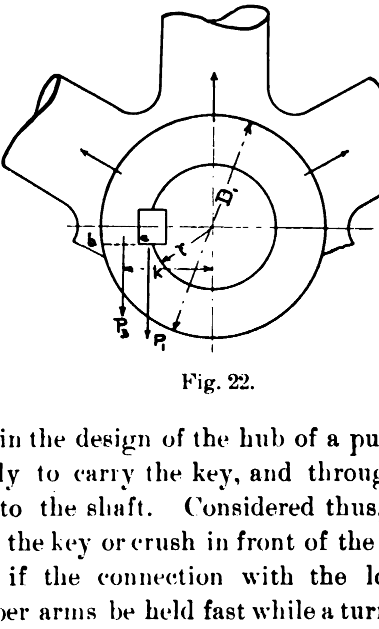


Fig. 22.

Pulley Hub. As in the case of the arms, centrifugal force does not play much part in the design of the hub of a pulley. The hub is designed principally to carry the key, and through it transmit the turning moment to the shaft. Considered thus, the hub may tear along the line of the key or crush in front of the key.

For example, in Fig. 22, if the connection with the lower arms be neglected, and the upper arms be held fast while a turning force P_1, at the surface of the shaft, is transmitted to the hub through the key, then the metal of the hub directly in front of the key is under crushing stress; and the metal along the line *eb*, from the corner to the outside, is under tensile stress. This condition is the worst that could possibly happen, because the bracing effect of the lower arms has been neglected, and the key is located between the arms.

Taking moments about the center of the shaft, the value of the force at the shaft circumference, or the "key pull," is:

$$P_1 = \frac{P\,R.}{r} \qquad (26)$$

Now $\frac{P_1}{P_3} = \frac{k}{r}$, k being the distance from the center of shaft to center of eb, and the area of metal which is subjected to the tearing action P_3 is $l \times eb$. Equating the external force to the internal resistance, and assuming that the stress is equally distributed over the area $l \times eb$, we have:

$$P_3 = \frac{r}{k} P_1 = \frac{r}{k} \times \frac{P\,R}{r} = S \times l \times e\,b;$$

or,

$$S = \frac{PR}{k \times l \times eb}. \qquad (27)$$

The intensity of crushing on the metal in front of the key, due to force P_1, depends upon the thickness of the key, and is properly discussed later under "Keys."

PRACTICAL MODIFICATION—Pulley Rim. The theoretical calculation for the thickness of the rim may give a thickness that could not be cast in the foundry, and the section in that case will have to be increased. As light a section as can be readily cast will usually be found abundantly strong for the forces it has to resist. A minimum thickness at the edge of the rim is about $\frac{3}{16}$ inch; and as the pulleys increase in size, the rim also must be made thicker; otherwise the rim will cool so much more quickly than the arms, that the latter, on cooling, will develop shrinkage cracks at the point of junction.

For a velocity of 6,000 feet per minute, we find from equation 18 that the tension in pounds per square inch, in the rim, due to centrifugal force, is 970. Though this in itself is a low value, yet the uncertain nature of cast iron, its condition of internal stress, due to casting, and the likely existence of hidden flaws and pockets, have established the usage of this figure as the highest safe limit for the peripheral speed of cast-iron pulleys. It is easily remembered that *cast-iron pulleys are safe for a linear velocity of about one mile per minute.*

To prevent the belt from running off the pulley, a "crown" or rounding surface is given the rim. A tapered face, which is more easily produced in the ordinary shop, may be used instead. This taper should be as little as possible, consistent with the belt staying on the pulley; ½ inch per foot each way from the center is not too much for faces 4 inches wide and less; while above this width ¼ inch per foot is enough. As little as ⅛ inch total crown has been found to be sufficient on a 24-inch face, but this is probably too little for general service.

Instead of being "crowned," the pulley may be flanged at the edges; but flanged pulley rims chafe and wear the edge of the belt.

The inside of the rim of a cast-iron pulley should have a taper of ½ inch per foot to permit easy withdrawal from the foundry mould. This is known as "draft." If the pattern be of metal, or if the pulley be machine-moulded, the greater truth of the casting does not require that the inside of the rim be turned, as the pulley, at low speeds, will be in sufficiently good balance to run smoothly. For roughly moulded pulleys, and for use at high speeds, however, it is necessary that the rim be turned on the inside to give the pulley a running balance.

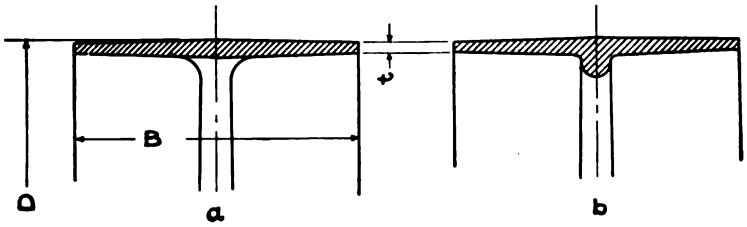


Fig. 23.

Fig. 23 shows a plain rim *a* also one stiffened by a rib *b*. Where heavy arms are used this rib is essential so that there will not be too sudden change of section at the junction of rim and arm, and consequent cracks or spongy metal.

Pulley Arms. The arms should be well filletted at both rim and hub, to render the flow of metal free and uniform in the mould. The general proportions of arms and connections to both hub and rim may perhaps be best developed by trial to scale on the drawing board. The base of the arm being determined, it may gradually taper to the rim, where it takes about the relation of $\frac{2}{3}$ to $\frac{3}{4}$ the dimensions chosen at the hub. The taper may be modified until it looks right, and then the sizes checked for strength.

Six arms are used in the great majority of pulleys. This number not only looks well, but is adapted to the standard three-jawed chucks and common clamping devices found in most shops. Elliptical arms look better than the segmental style. The flat, rectangular arm gives a very clumsy and heavy appearance, and is seldom found except on the very cheapest work.

A double set of arms may be used on an excessively wide face, but it complicates the casting to some extent.

Although a web pulley may be calculated for shear at the hub, yet it will usually be found that with a thickness of web intermediate between the thickness of the rim and that of the hub, which will satisfy the casting requirements, the requirements as to strength will be fully met.

Pulley Hub. The hub should have a taper of $\frac{1}{2}$ inch per foot draft, similar to that of the inside of the rim. The length of the hub is arbitrary, but should be ample to prevent rocking on the shaft. A common rule is to make it about $\frac{3}{4}$ the face width of the pulley.

The diameter of the hub, aside from the theoretical consideration given above, must be sufficient to take the wedging action of a taper key without splitting. This relation cannot well be calculated. Probably the best rule that exists is the familiar one that the hub should be twice the diameter of the shaft. This rule, however, cannot be literally adhered to, as it gives too small hubs for small shafts and too large ones for large shafts. It is always well to locate the key, if possible, underneath an arm instead of between the arms, thus gaining the additional strength due to the backing of the arm.

SPLIT PULLEYS.

ANALYSIS and THEORY. The split pulley is made in halves and provided with bolts through flanges and bosses on the hub for holding the two halves together. When the pulley is in place on the shaft, bolted up as one piece, it is subjected to the same forces as the simple pulley. Hence its general design follows the same principles, and we need only study the fastening of the two halves, and the effect of this fastening on the detail of rim and hub.

The simplest stress we have to consider on the rim bolts is one of pure tension, due to the centrifugal force of the halves of the pulley, A safe assumption to make is that the rim is free from the arms and hub, as in the simple pulley, and that the centrifugal force developed by it has to be taken by the rim bolts alone. In other words, consider the rim bolts as belonging entirely to the rim, and make them as strong as the rim, leaving the hub bolts to take the centrifugal force of the arms and hub, and the spreading tendency due to the key.

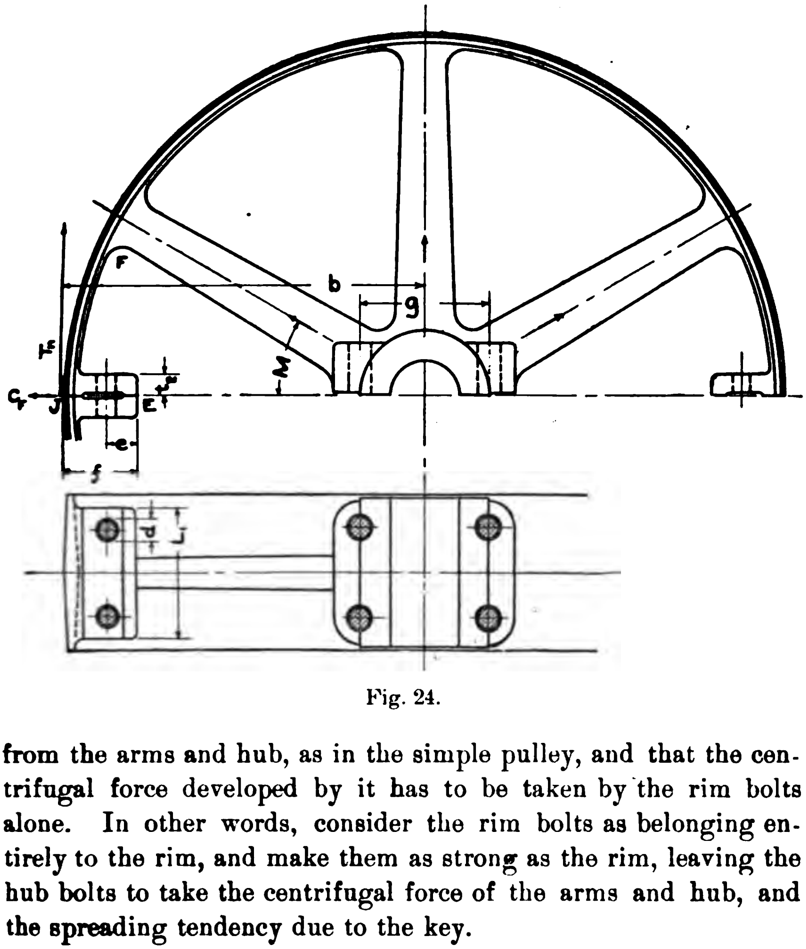


Fig. 24.

Another tensile stress is induced in the rim bolts by the fact, that, having made an open joint in the rim, and in addition placed the extra weight of lugs there, the centrifugal action at this point is increased, and at the same time a point of weakness in the rim introduced. Referring to Fig. 24, the rim flanges EJ tend to fly out due to the centrifugal force C_F. This tends to open the joint J at the outside of the rim; to throw a bending stress on the rim, maximum at the point F; and to "heel" the rim flanges about the point E. The rim bolts acting on the leverage *e* about the point E must resist these tendencies, and are thereby put in tension.

Referring to equation 18, we find the intensity of stress due to the centrifugal force of the rim in lbs. per square inch to be:

$$p = \frac{v^2}{10}.$$

If A is the sectional area of the rim in square inches, this means that the total strength of the rim is represented by $\frac{Av^2}{10}$. The strength of a bolt is represented by the expression $\frac{S\pi d_1^2}{4}$. If, now, there are n bolts in the flange, the total resisting force of the bolts is $\frac{nS\pi d_1^2}{4}$; and the equation representing equality of strength between rim and bolts is:

$$\frac{Av^2}{10} = \frac{nS\pi d_1^2}{4}, \quad (28)$$

from which, by a proper assumption of the fiber stress S, which should be low, the opening-up tendency of the joint being neglected, the diameter at the root of the thread d_1 may be calculated, and the nominal bolt diameter chosen. Reference to the table for strength of bolts, given in the chapter on Bolts, Studs, etc., will be found convenient.

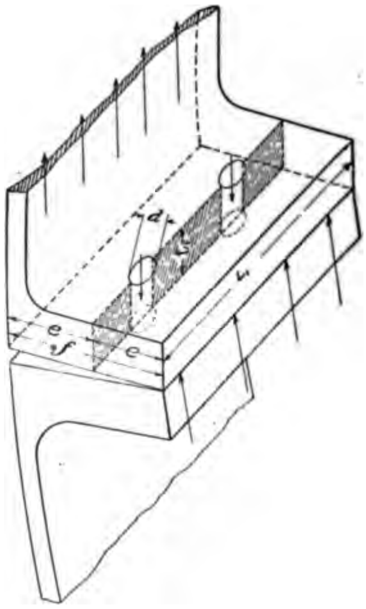
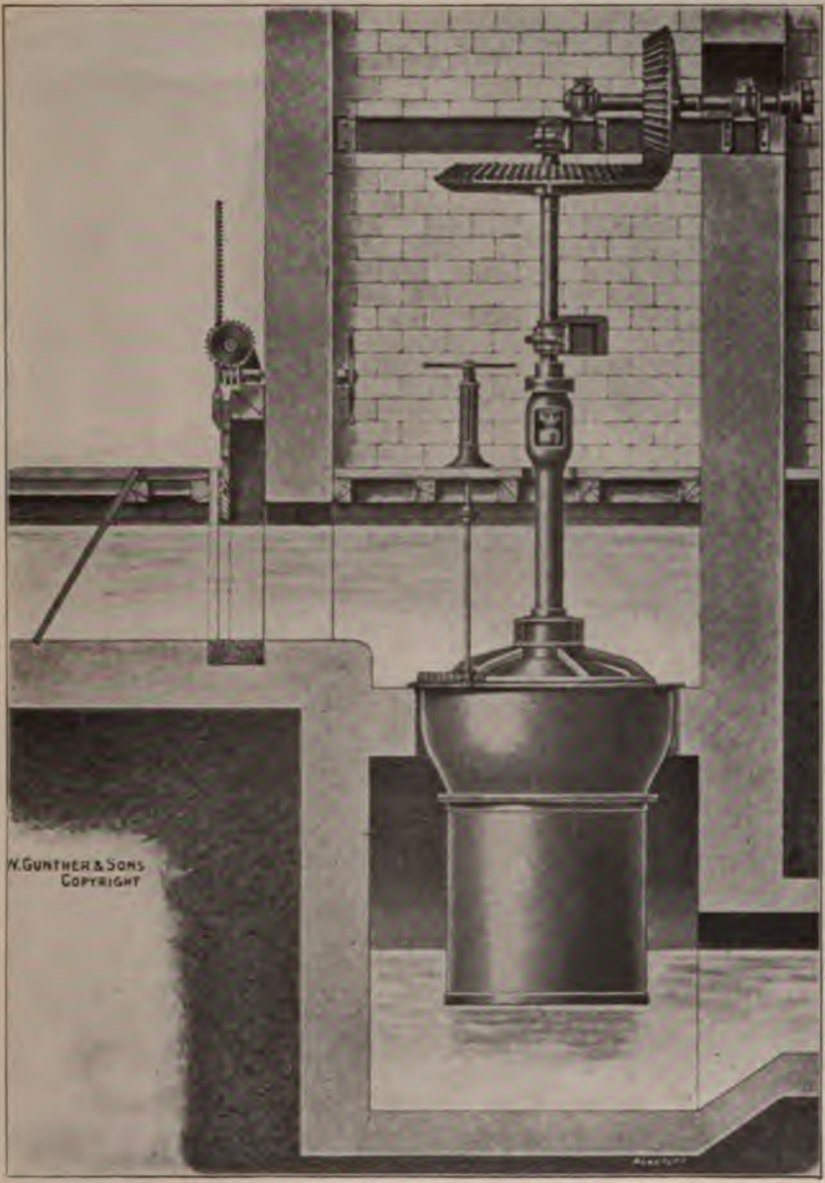


Fig. 25.



GENERAL ARRANGEMENT OF JONVAL TURBINE.
Central Engineering Works, Oldham, Eng.

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ASTOR, LENOX

It is very doubtful if the tension on the flange bolts, due to the "heeling" about E can be calculated with sufficient accuracy to be of much value. It is probably better to assume S at a low value, say 4,000, and, in addition, for large and high-speed pulleys, stiffen the rim by running a rib between the flange and the adjacent arm. It is evident that if we make the rim so stiff that it cannot deflect, there will be no "heeling" about E; and the bolts will be well proportioned by the preceding calculation, giving them equal strength to that of the rim section.

For the bolt flange itself, any tendency to open at the joint J would cause it to act like a beam loaded at some point near its middle with the bolt load, and supported at J and E. This condition is shown in Fig. 25. Probably the weakest section would be along the line of the bolt centers. We have just noted that the carrying capacity of the bolts is $\frac{nS\pi d_1^2}{4}$ Hence, assuming that $e = \frac{1}{2}f$, which is about the worst case which could happen, we have a beam of length f loaded at the middle with $\frac{nS\pi d_1^2}{4}$ and supported at the ends. Equating the external moment to the internal moment, we have:

$$\frac{nS\pi d_1^2}{4} \times \frac{f}{4} = \frac{s(L_1 - nd)t_2^2}{6}, \qquad (29)$$

from which the fiber stress s in the flange may be calculated and judged for its allowable value.

L_1 may be assumed a little narrower than the pulley face; and t_2 from 1 inch to 2 inches or more, depending on the thickness of the rim.

The hub bolts doubtless assist the rim bolts in preventing the halves of the pulley from flying apart. They also clamp the hub tightly to the shaft, preventing any looseness on the key. Their function is a rather general one; and the specific stress which they receive is practically impossible to calculate. As a matter of fact, if the hub bolts were left out entirely, the pulley would still drive fairly well, but general rigidity and steadiness would be impaired. Hence the size of the hub bolts is more a practical question than one involving calculation. The rim bolts should be figured first, and their size determined on; then the hub bolts can be judged in proportion to the rim bolts, the diameter of shaft, the thickness and length of the hub, and the general form of the pulley. Often appearance is the deciding factor, it being manifestly inconsistent to associate small fastenings with large shafts or hubs, even though the load be actually small.

PRACTICAL MODIFICATION. Practical considerations are chiefly responsible for the location of the joint in a split pulley between the arms instead of directly at the end of an arm, where theoretically it would seem to be required. It is usually more convenient in the foundry and machine shop to have the joint between the arms; so we generally find it placed there, and strength provided to permit this. It is possible, however, to provide a double arm, or a single split arm, in which case the joint of the pulley comes at the arm, and the "heeling" action of the rim flanges is prevented.

The rim bolts should be crowded as close as possible to the rim in order to reduce the stress on them, and also the stress in the flange itself. The practical point must not be forgotten, however that the bolts must have sufficient clearance to be put into place beneath the rim.

While it is evident that the rim bolts are most effective in taking care of the centrifugal action of the halves, yet in small split pulleys it is quite common to omit the rim bolts and to use the hub bolts for the double purpose of clamping the shaft and holding the two halves together. The pulley is cast with its rim continuous throughout the full circle, and it is machined in this form. It is then cracked in two by a well-directed blow of a cold chisel, the casting being especially arranged for this along the division line by cores so set that but a narrow fin of metal holds the two parts together. This provides sufficient strength for casting and turning, but permits the cold chisel to break the connection easily.

SPECIAL FORMS OF PULLEYS.

The plain cast-iron pulley has been used in the foregoing discussion as a basis of design. A pulley is, however, such a common commercial article, and finds such universal use, that special forms, which can be bought in the open market, are not only cheaper but better than the plain cast-iron pulley, at least for regular line-shaft work.

Cast iron is a treacherous and uncertain material for rims of pulleys. It is not well suited to high fiber stresses; hence the range of speed permissible for pulley rims of cast iron is limited. Steel and wrought iron, having several times the tensional strength of cast iron, and being, moreover, much more nearly homogeneous in texture, are well suited for this work; one of the best pulleys on the market consists of a steel rim riveted to a cast-iron spider. Such an arrangement combines strength and lightness, without increasing complication or expense.

The all-steel pulley is a step further in this direction. Here the rim, arms, and hub are each pressed into shape by specially devised machinery, then riveted and bolted together. This pulley is strictly a manufactured article, which could not compete with the simpler forms unless built in large quantities, enabling automatic machinery to be used. Large numbers of pulleys are built in this way, and are put on the market at reasonable prices.

Wood-rim pulleys have been made for many years, and, except for their clumsy appearance, are excellent in many respects. The rim is built up of segments in much the same way as an ordinary pattern is made, the segments being so arranged that they will not shrink or twist out of shape from moisture. The hubs may be of cast iron, bolted to wooden webs, and carrying hardwood split bushings, which may be varied in bore within certain limits so as to fit different sizes of shafting. The wooden pulley is readily and most often used in the split form, thus enabling it to be put in position easily at any point of a crowded shaft. It is often merely clamped in place, thus avoiding the use of keys or set screws, and not burring or roughening the shaft in any way.

PROBLEMS ON PULLEYS.

1. Calculate the tensile stress due to centrifugal force in the rim of a cast-iron pulley 30 inches in diameter, at 500 revolutions per minute.

2. The driving force of a belt on a 36-inch pulley is 800 lbs., and the belt wrap about 180°. Calculate proportions of el-

liptical arms to resist bending, the allowable fiber stress being 2,000.

3. A pulley 12 inches in diameter, $\frac{5}{8}$-inch web, 4-inch diameter hub, transmits 25 horse-power at a belt speed of 3,000 ft. per minute. Calculate the maximum shearing stress in the web.

4. In Fig. 24 assume the following data: $L_1 = 7$ inches; $t_2 = 1$ inch; $e = 1\frac{1}{2}$ inches; $f = 3$ inches; area of rim = 3 sq. in.; allowable tensile stress in rim 1,000 lbs. per sq. in. Calculate the diameter of the rim bolts.

5. Calculate the fiber stress in the rim bolt flange along the line of the bolts.

SHAFTS.

NOTATION—The following notation is used throughout the chapter on Shafts:

A_a = Angular deflection (degrees).
B = Simple bending moment (inch-lbs.).
B_e = Equivalent bending moment (inch-lbs.).
c = Distance from neutral axis to outer fiber (inches).
d, d_0, d_2, d_3, d_4 = Diameters of shaft (inches).
d_1 = Internal diameter of shaft (inches).
E = Direct modulus of elasticity (a ratio).
e = Transverse deflection (inches).
G = Transverse modulus of elasticity (a ratio).
H = Horse-power (33,000 ft.-lbs. per minute).
I = Moment of inertia.
K = Distance between bearings (inches).
L = Length along shaft (inches).
L_1, L_2 = Length of bearings (inches.)
M = Distance between bearings (feet.)
N = Number of revolutions per minute.
P = Driving force of belt (lbs.).
P_1 = Load applied as stated (lbs.).
R = Radius at which load as stated acts (inches).
S = Fiber stress, tension, compression, or shearing (lbs. per sq. in.).
T = Simple twisting moment (inch-lbs.).
T_e = Equivalent twisting moment (inch-lbs.).
T_n = Tension in tight side of belt (lbs.).
T_o = Tension in loose side of belt (lbs.).
W = Load applied as stated (lbs.).

ANALYSIS. The simplest case of shaft loading is shown in Fig. 26. The equal forces W, similarly applied to the disc at the distance R from its center, tend to twist the shaft off, the tendency being equal at all points of the length L between the disc and the post, to which the shaft is rigidly fastened. The fastening to the post, of course, in this ideal case, takes the place of a resisting member of a machine. A state of pure torsion is induced in the shaft; and any element, such as *ca*, is distorted to the position *cb*, *aob* being the angular deflection for the distance L.

The case of Fig. 27 is illustrative of what occurs when a belt pulley is substituted for the simple disc. Here the twisting action is caused by the driving force of the belt, which is $T_n - T_o = P$, acting at the radius R. Torsion and angular deflection exist in the shaft, as in Fig. 26. In addition, however, another stress of a different kind has been introduced; for not only does the shaft tend to be twisted off, but the forces T_n and T_o, acting together, tend to bend the shaft, the bending moment varying with every section of the shaft, being nothing at the point *o*, and maximum at the point *c*. This combined action is the most common of any that we find in ordinary machinery, occurring in nearly every case with which we have to deal.

In Fig. 27, if the forces T_n and T_o be made equal, there will be no tendency at all to twist off the shaft, but the bending will remain, being maximum at the point *c*. This condition is illustrative of the case of all ordinary pins and studs in machines. In this sense, a pin or a stud is simply a shaft which is fixed to the frame of the machine, there being no tendency to turning of the pin or stud itself. The same condition would be realized if the disc in Fig. 27 were loose upon the shaft. In that case, the bending moment would be caused by $T_n + T_o$ acting with the leverage L. Of course there would have to be some resistance for $T_n - T_o$ to work against, in order that torsion should not be transmitted through the shaft. This condition might be introduced by having a similar disc lock with the first one by means of lugs on its face, thus receiving and transmitting the torsion.

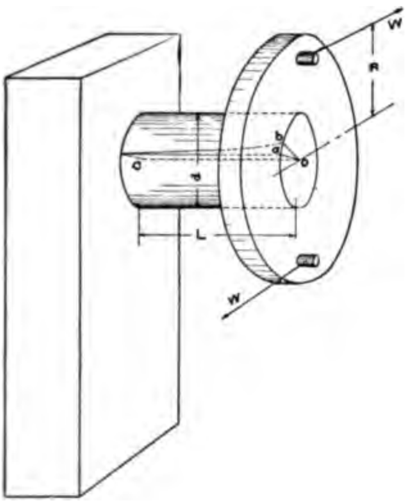

Fig. 26.

If the distance L becomes very great, both the angular deflection due to twisting, and the sidewise deflection due to bending, become excessive, and not permissible in good design. This trouble is remedied by placing a bearing at some point closer to the disc, which, as it decreases L, of course, decreases the bending moment and therefore the transverse deflection. The angular de-

be decreased only by bringing the resistance and load
ner.

ve implies, of course, that the diameter of the shaft is not
chan- ing obvious that increase of diameter means increase of strength
and ling decrease of both angular and transverse deflection.

peed of the shaft be very high, and the distance between bearı gs, represented by L, be very great, the shaft will take a pe like a bow string when it is vibrated, and smooth action cannot be maintained.

It is necessary to carry the cases of Figs. 26 and 27 but a

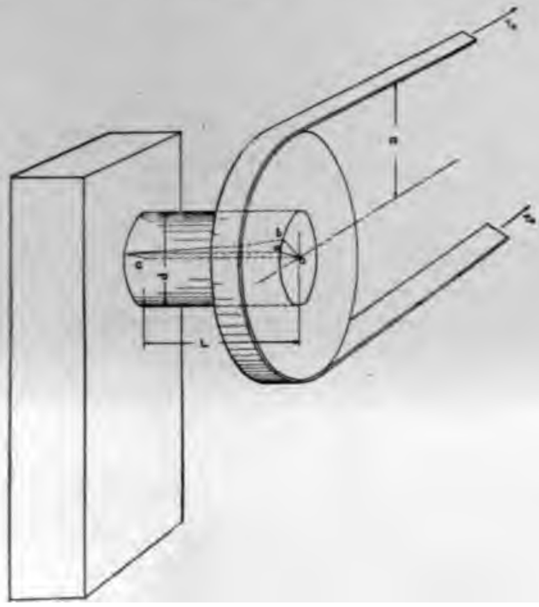

Fig. 27.

single step farther to illustrate the actual working conditions o shafting in machines. Suppose the rigid post to have the shaf passing clear through it, and to act as a bearing, so that the shaft can freely rotate in it, the resistance being exerted somewhere beyond. The twisting moment will be unchanged, also the bending moment; but the effect of the bending moment will be on each particle of the shaft in succession, now putting compression on a given particle, and then tension, then compression again, and so on, a complete cycle being performed for each revolution. This brings out a very important difference between the bending stress in pins and the bending stress in rotating shafts. In the one case the bending stress is non-reversing; in the other, reversing; and a much higher fiber stress is permissible in the former than in the latter.

THEORY—Simple Torsion. In the case of simple torsion the stress induced in the shaft is a shearing one. The external moment acts about the axis of the shaft, or is a polar moment; hence in the expression for the moment of the internal forces, the polar moment of inertia must be used. Now, from mechanics we have:

$$T = \frac{S\,I}{c};$$

and $$\frac{I}{c} = \frac{d^3}{5.1} \text{ (for circular section of diameter } d\text{);}$$

therefore, $$T = \frac{Sd^3}{5.1}, \qquad (30)$$

from which the diameter for any given twisting moment and fiber stress can readily be found.

For a hollow shaft this expression becomes:

$$T = \frac{S(d_o^4 - d_1^4)}{5.1d_o}. \qquad (31)$$

Simple Bending. The stresses induced in a pin or shaft under simple bending are compression and tension. The external moment in this case is transverse, or about an axis across the shaft; hence the direct moment of inertia is applicable to the equation of forces.

$$B = \frac{S\,I}{c};$$

and $$\frac{I}{c} = \frac{d^3}{10.2} \text{ (for circular section of diameter } d\text{);}$$

therefore, $$B = \frac{Sd^3}{10.2}. \qquad (32)$$

For a hollow shaft or pin this expression becomes:

$$B = \frac{S(d_o^4 - d_1^4)}{10.2d_o}. \qquad (33)$$

Combined Stresses. In the greater number of cases met with in practice, we find two or more simple stresses acting at the same time, and, although the shaft may be strong enough for any one of them alone, it may fail under their combined action. The most common cases are discussed below.

Tension or Pressure Combined with Bending. In Fig. 28, the load W produces a tension acting over the whole area of d, due to its direct pull. It also produces a bending action due to the leverage R, which puts the fibers at B in tension and those at the opposite side in compression. It is evident, therefore, that by taking the algebraic sum of the stresses at either side we shall obtain the net stress. It is also evident that the greatest and controlling stress will occur on the side where the stresses add, or on the tension side. Hence, from mechanics,

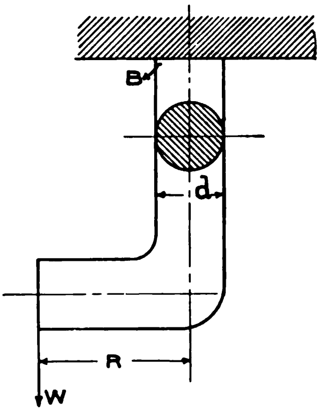

Fig. 28.

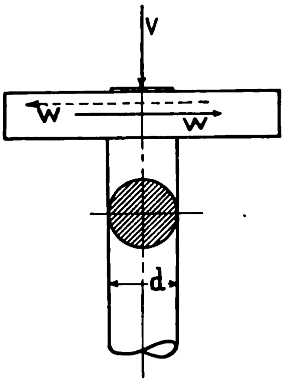

Fig. 29

$$W = \frac{\pi d^2 S}{4};$$

or, $$S = \frac{4W}{\pi d^2} \text{ (due to direct tension).} \quad \mathbf{(34)}$$

Also, $$WR = \frac{Sd^3}{10.2};$$

or, $$S = \frac{10.2\ WR}{d^3} \text{ (due to bending).} \quad \mathbf{(35)}$$

Hence the combined tensional stress acting at the point B, or, in fact, at any point on the extreme outside of the vertical shaft toward the force W, is:

$$S = \frac{4W}{\pi d^2} + \frac{10.2\ WR}{d^3}. \qquad (36)$$

If W acted in the opposite direction, the greatest stress would still be at the side B, but would be a compression instead of a tension, of the same magnitude as before.

Tension or Compression Combined with Torsion. In Fig. 29, V might be the end load on a vertical shaft; and the two forces W might act in conjunction with it as in the case of Fig. 26, at the radius R. This case is not very often met with. It is usually possible to combine the moments, find an equivalent moment of a simple kind, and use the corresponding simple fiber stress. In the case in question we have a direct stress to be combined with a shearing stress, and mechanics gives us the following solution:

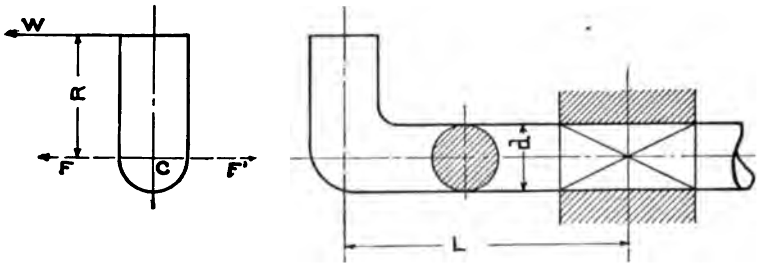

Fig. 30.

Let S_s = simple shearing stress (lbs. per sq in.).
Let S_c = simple compressive stress (lbs. per sq. in.).
Let S_{rs} = resultant shearing stress (lbs. per sq. in.).
Let S_{rc} = resultant compressive stress (lbs. per sq. in.).

We then have :

$$2WR = \frac{S_s d^3}{5.1};$$

or,

$$S_s = \frac{5.1(2WR)}{d^3}. \qquad (37)$$

Also,

$$V = \frac{\pi d^2 S_c}{4};$$

or, $$S_c = \frac{4}{\pi d^2} V. \qquad (38)$$

Now, from a solution given in simplest form in "Merriman's Mechanics"—which the student may consult, if desired—values for the resultant stresses can be found. Whichever of these is the critical one for the material used, should form the basis for its diameter:

$$S_{rs} = \sqrt{S_s^2 + \frac{S_c^2}{4}}. \qquad (39)$$

Also, $$S_{rc} = \frac{S_c}{2} + \sqrt{S_s^2 + \frac{S_c^2}{4}}. \qquad (40)$$

Bending Combined with Torsion. In Fig. 30, the load W acts not only to twist the shaft off, but also presses it sidewise against the bearing. As it is usually customary to figure the maximum moment as taking place at the center of the bearing, the length L, which determines the bending moment, is taken to that point. The theory of the stress induced in this case is complicated. In order to make the magnitude of the moments clearer, let us introduce the two equal and opposite forces F and F^1, each equal to W, at the point C. We can evidently do this without changing the equilibrium of the shaft in any way. We now see that W and F^1 act as a couple giving a twisting moment WR; and that F acts with a leverage L, producing a bending moment FL = WL, at the middle of the bearing.

If, now, we find an equivalent twisting moment, or an equivalent bending moment, which would produce the same effect on the fibers of the shaft as the two combined, we can treat the calculation of the diameter as a simple case, and proceed as in the cases of simple torsion and simple bending considered above. This relation is given us in mechanics:

$$B_e = \frac{B}{2} + \frac{1}{2}\sqrt{B^2 + T^2}. \qquad (41)$$

$$T_e = B + \sqrt{B^2 + T^2}. \qquad (42)$$

These expressions are true in relation to each other, on the assumption that the allowable fiber stress S is the same for tension, compression, and shearing. For the material of which shafts are usually made, this is near enough to the truth to give safe and practical results. Using the expressions for internal moments of resistance as previously noted for circular sections, we then have :

$$B_e = \frac{Sd^3}{10.2}. \qquad (43)$$

Also,

$$T_e = \frac{Sd^3}{5.1}. \qquad (44)$$

Either equation may be used ; the diameter d will result the same whichever equation is taken. For the sake of simplicity, equation 42 is generally preferred, equation 44 being taken in conjunction with it.

The expression $\sqrt{B^2 + T^2}$ is one that would be a long and tedious task to calculate. By inspection it is readily seen that this quantity can be graphically represented by means of a right-angled triangle having B and T as the sides. We may then lay down on a piece of paper, to some convenient scale, the moments B and T as the sides of a right-angled triangle, when, upon measuring the hypothenuse, we can easily read off to the same scale $\sqrt{B^2 + T^2}$. Even if the drawing is made to a small scale, the accuracy of the reading will be sufficient to enable the value for d to be solved very closely. This graphical method is illustrated in Part I.

Deflection. For a shaft subjected to pure torsion, as in Fig. 26, the angular deflection due to the load may be carried to a certain point before the limit of working fiber stress is exceeded. The equation worked out from mechanics for this condition, is:

$$A^{\circ} = \frac{584\ TL}{Gd^4}, \qquad (45)$$

which at once gives the number of degrees of angular deflection for a shaft whose modulus of elasticity, torsional moment, and length are known.

The shearing modulus of elasticity of ordinary shaft steel runs from 10,000,000 to 13,000,000, giving as an average about 12,000,000.

By the well-known relation of "Hooke's law" (stresses proportional to strains within the elastic limit of the material), we have:

$$\frac{A^\circ}{360^\circ} = \frac{SL}{\pi G d};$$

or

$$S = \frac{A \pi G d}{360\ L}. \qquad (46)$$

A twist of one degree in a length of twenty diameters is a usual allowance. Substituting $A = 1$, $L = 20d$, and $G = 12{,}000{,}000$, we have:

$$S = 5{,}240 \text{ (nearly)}. \qquad (47)$$

This is a safe value for shearing fiber stress in steel. In fact, in calculations for strength, even for reversing stresses, the usual figure is 8,000 (lbs. per square inch), thus indicating that the relation of one degree to twenty diameters is well within the limit of strength.

For a hollow shaft the above formula becomes :

$$A^\circ = \frac{584\ TL}{G(d_0^4 - d_1^4)}. \qquad (48)$$

Transverse deflection occurs when the shaft is subjected to a bending moment. It may therefore exist alone or in conjunction with angular deflection. Transverse deflection of shafts, however, rarely exists up to the point of limiting fiber stress, because before that point is reached the alignment of the shaft is so disturbed that it is not practicable as a device for transmitting power. A transverse deflection of .01 inch per foot of length is a common allowance ; but it is impossible to fix any general limit, as in many cases this figure, if exceeded, would do no harm, while in others—such as heavily loaded or high-speed bearings—even the figure given might be fatal to good operation.

The formula for transverse deflection, deduced from mechanics, varies with the system of loading. The three most common conditions only are given below, reference to the handbook being necessary if other conditions must be satisfied:

Fixed at one end, loaded at the other,

$$e = \frac{WL^3}{3\ EI}. \qquad (49)$$

Supported at ends, loaded in middle,

$$e = \frac{WL^3}{48EI}. \qquad (50)$$

Supported at ends, loaded uniformly,

$$e = \frac{5WL^3}{384EI}. \qquad (51)$$

For transverse deflection the direct modulus of elasticity must be used, for the fibers are stretched or compressed, instead of being subjected to a shearing action. The most usual value of the direct modulus of elasticity for ordinary steel is 30,000,000, and is denoted in most books by the symbol E. Both the shearing and direct moduli of elasticity are really nothing but the ratio of the stress to the strain produced by that stress, it being assumed that the given material is perfectly elastic. A material is supposed to be perfectly elastic up to a certain limit of stress, and it is within this limit that the relation as above holds good.

Expressed in the form of an equation this would be:

$$E = \frac{S}{\frac{e}{L}} = \frac{SL}{e}. \qquad (52)$$

Centrifugal Whirling. If a line shaft deflect but slightly, due to its own weight, or the weight or pressure of other bodies upon it, and then be run at a high speed, the centrifugal force set up increases the deflection, and the shaft whirls about the geometrical line through the centers of the bearings, causing vibration and wear in the adjoining members. It is evident that the practical remedy for this tendency in a shaft of given diameter and speed is to locate the bearings sufficiently close to render the action of small effect.

Many formulæ might be given for this relation, each being based on different assumptions. Perhaps as widely applied and as simple as any, is the "Rankine" formula, which sets the limit of length between bearings for shafts not greatly loaded by intermediate pulleys or side strains:

$$M = 175 \sqrt{\frac{d}{N}}. \qquad (53)$$

Horse-Power of Shafting. Horse-power is a certain specific rate of doing work, *viz.*, 33,000 foot-pounds per minute. Hence, to find the horse-power that a shaft will transmit, we must first find the work done, and then relate it to the speed. Take, for example, the case of a pulley, the symbols being the same as before —namely, P = driving force at rim of pulley (lbs.); R = radius of pulley (inches); N = number of revolutions per minute; and H = horse-power. Then,

$$\text{Work} = \text{force} \times \text{distance} = P \times (2\pi RN) = H \times 33{,}000 \times 12;$$

or,

$$PR = \frac{63{,}025H}{N}. \qquad (54)$$

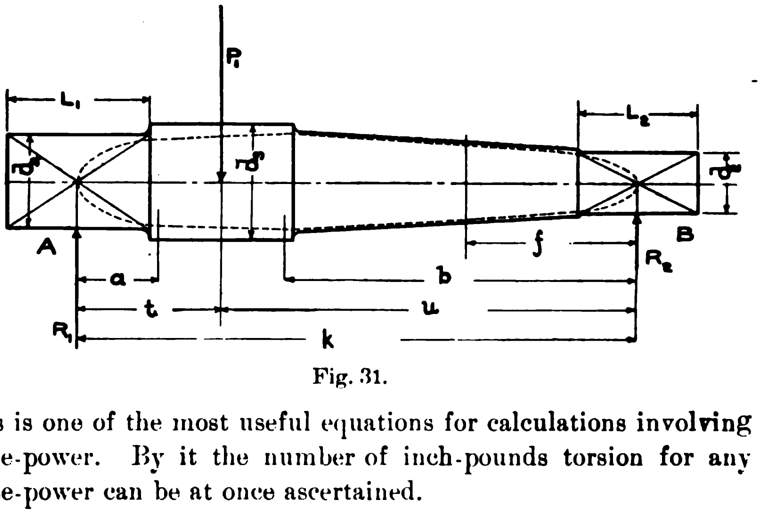

Fig. 31.

This is one of the most useful equations for calculations involving horse-power. By it the number of inch-pounds torsion for any horse-power can be at once ascertained.

It should be clearly noted, however, that in this equation the bending moment does not enter at all. Hence any shaft based in size on *horse-power alone*, is based on *torsional moment alone*, bending moment being entirely neglected. In many cases the bending moment is the controlling one as to limiting fiber stress. Hence empirical shafting formulæ depending upon the horse-power relation are unsafe, unless it is definitely known just what torsional and bending moments have been assumed.

The only safe way to figure the size of a shaft is to find accurately what torsional moment and bending moment it has to sustain, and then combine them according to equation 41 or 42 introducing the element of speed as basis for assumption of a high or low working fiber stress.

PRACTICAL MODIFICATION. The practical methods of handling the theoretical shaft equations have reference to the fit of the shaft within the several pieces upon it. The running fit of a shaft in a bearing is usually considered to be so loose that the shaft could freely deflect to the center of the bearing. This is doubtless an extreme view of the case, but it is the only safe assumption. Hence a shaft running in bearings (see Fig. 31) is supposed to be supported at the centers of those bearings, and its theoretical strength is based on this supposition.

For a tight or driving fit upon the shaft, a safe assumption to make is that there is looseness enough at the ends of the fit to permit the shaft to be stressed by the load a short distance within the faces of the hub, say from ½ inch to 1 inch. For example, referring to Fig. 31, suppose P_1 to be the transverse load, exerted through a hub fast upon the part of the shaft d_2. Taking moments about the center of one bearing, and solving for the reaction at the center of the other, we have :

$$P_1\,u = R_1\,K;$$

or,

$$R_1 = \frac{P\,u}{K}. \qquad (55)$$

Also,

$$P_1\,t = R_2\,K;$$

or,

$$R_2 = \frac{P_1\,t}{K}. \qquad (56)$$

Now, as far as the part of shaft d_3 is concerned, it may depend for its size on the bending moment $R_2\,b$, or on $R_1\,a$. The reason the lever arm is not taken to the point directly under the load P_1, is because it is not practically possible to break the shaft at that point, on account of the reinforcement of the hub, which is tightly fitted upon it. Trying these moments to see which is the greater, we shall find that the greater moment always occurs in connection with the longer lever arm. Hence $R_2\,b$ will be greater than $R_1\,a$. We then write the equation of *external moment* = *internal moment:*

$$R_2\,b = \frac{S\,d_3^3}{10.2}\,;$$

or,
$$d_3 = \sqrt[3]{\frac{10.2\ R_2 b}{S}}. \qquad (57)$$

For the size of bearing A we have the maximum bending moment:

$$R_1 \frac{L_1}{2} = \frac{S\, d_4^3}{10.2};$$

or,
$$d_4 = \sqrt[3]{\frac{10.2\ R_1 L_1}{2\,S}}. \qquad (58)$$

For the size of bearing B we have the maximum moment:

$$R_2 \frac{L_2}{2} = \frac{S\, d_2^3}{10.2};$$

or,
$$d_2 = \sqrt[3]{\frac{10.2\ R_2 L}{2\,S}}. \qquad (59)$$

The above calculations are, of course, on the assumption that no torsion is transmitted either way through this axle. We should in that case have combined torsion and bending. This has been made sufficiently clear in preceding paragraphs and in Part I, to require no further illustration.

The dotted line in Fig. 31 shows the theoretical shape the axle should take under the assumed conditions. The practical modification of this shape is obvious. At the shoulders of the shaft the corners should not be sharp, but carefully filleted, to avoid the possible starting of a crack at those points.

Often the diameter of certain parts of a shaft may be larger than strength actually calls for. For example, in Fig. 31, the part d_3 need only be as large as the dotted line; but it is obvious that unless the key is sunk in the body of the shaft, the hub could not be slipped into place over the part d_4. If, however, the diameter d_3 be made large enough so that the bottom of the key will clear d_4, the rotary cutter which forms the key way in d_3 will also clear d_4, and the key way can be more easily produced.

In cases where fits are not required to be snug, a straight shaft of cold-rolled steel is commonly used. Here any parts fastened on the middle of the shaft have to be driven over a considerable length of the shaft before they reach their final position. Moreover, there is no definite shoulder to stop against, and measurement has to be resorted to in locating them.

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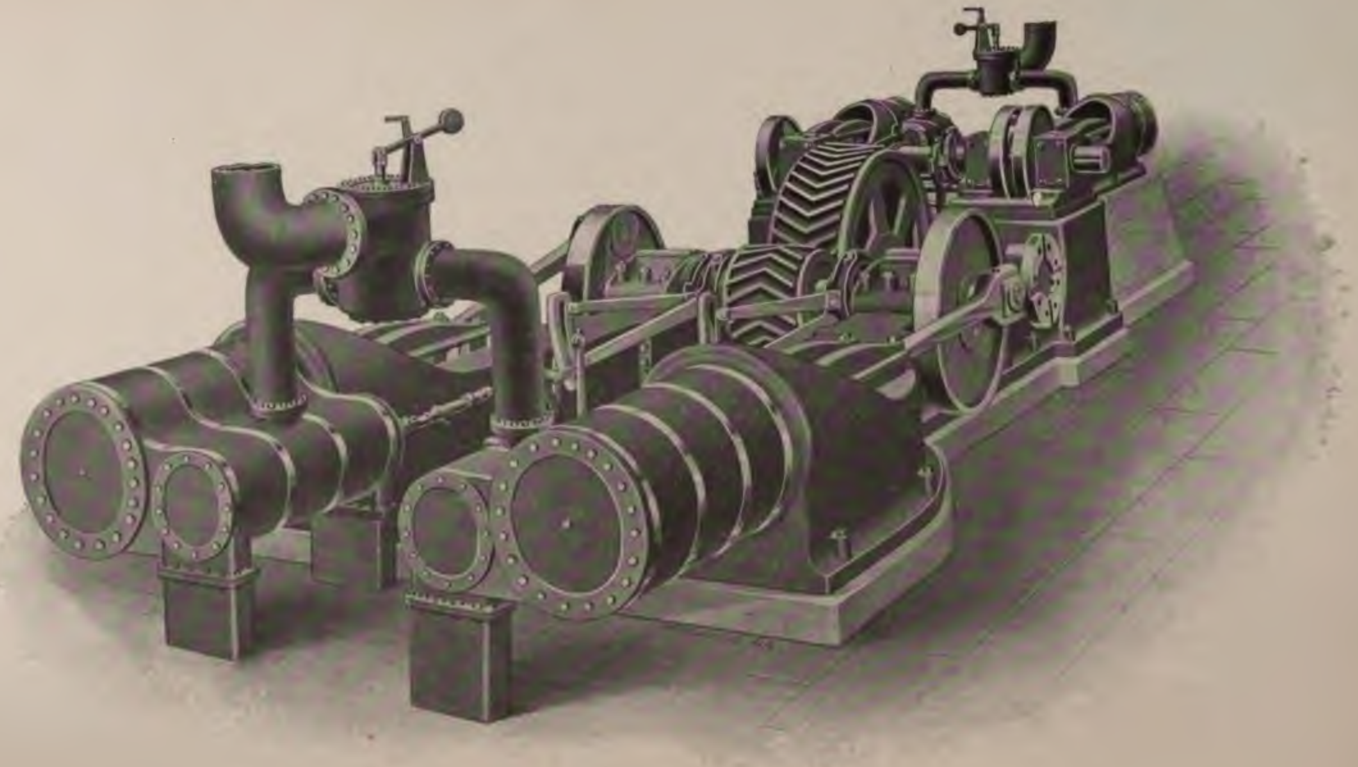


UNIVERSAL SLABBING MILL ENGINES.
46 x 60 inches and 26 x 30 inches
William Tod Co

It does not pay to turn any portion of a cold-rolled shaft, unless it be the very ends, for relieving the "skin tension" in such material is sure to throw the shaft out of line and necessitate subsequent straightening.

Turned-steel shafts for machines may with advantage be slightly varied in diameter wherever the fit changes; and although the production of shoulders costs something, yet it assists greatly in bringing the parts to their exact location, and enables the workman to concentrate his best skill on the fine bearing fits, and to save time by rough-turning the parts that have no fits.

Hollow shafts are practicable only for large sizes. The advantages of removing the inner core of metal, aside from some specific requirement of the machine, are that it eliminates all possibility of cracks starting from the checks that may exist at the center, permits inspection of the material of a shaft, and, in case of hollow-forged shafts, gives an opening for the forging mandrel. In the last case, the material is improved by a rolling process.

The material most common for use in machine shafting is the ordinary "Machinery Steel," made by the Bessemer process. This steel is apt to be "seamy," and often contains checks and flaws that are detected only upon sudden and unexpected breakage of a part apparently sound. This characteristic is a result of the process employed in the manufacture of the steel, and thus far has never been wholly eliminated. **Bessemer steel** is, nevertheless, a very useful material, and the above weakness is not so serious but that this kind of steel can be used with success in the great majority of cases.

When a more homogeneous shaft is desired, **open-hearth steel** is available. This is a more reliable material to use than the Bessemer, and costs somewhat more. It makes a stiff, true, fine-surfaced shaft, high-grade in every respect. It is usually specified for armature shafts of dynamos and motors.

Steels of special strength, toughness, and elasticity are made under numerous processes. **Nickel steel** is perhaps the most conspicuous example. While for this steel a high price has to be paid, yet its great strength, in connection with other valuable qualities, makes it a material extremely valuable for service where light weight is essential, or where contracted space demands small size.

The range of strength of these various steels is so great that it is well-nigh useless to go into a discussion of it here. Reference should be had to the extended discussions of the handbooks, and to special trade pamphlets. A study of the possibilities of steel in its various forms for use in shafting, is very valuable as a basis for design, as it can almost be said that a machine consists chiefly of a "collection of shafts with a structure built round them." The shafts are like a core, and evidently the size of the core determines the shell about it.

PROBLEMS ON SHAFTS.

1. Required the twisting moment on a shaft that transmits 30 horse-power at 120 revolutions per minute.

2. Find the diameter of a steel shaft designed to transmit 50 horse-power at 150 revolutions per minute.

3. Assuming same data as in Problem 1, find the diameters of a hollow shaft for a value of $S = 8{,}000$.

4. A belt on an idler pulley embraces an angle of 120 degrees. Assuming tension of belt 1,000 pounds on each side, and pulley located midway between bearings, which are 30 inches from center to center, what is the diameter of shaft required?

5. Calculate the diameter of a steel shaft designed to transmit a twisting moment of 400,000 inch-pounds and also to take a bending moment of 300,000 inch-pounds.

6. Find the angular deflection in a 4-inch shaft 20 feet long when subjected to a load of 5,500 pounds applied to an arm of 30-inch radius. Assume transverse modulus of elasticity equal to 12,000,000.

7. The overhung crank of a steam engine has a force of 32,000 lbs. at the center of the crank pin, which is 12 inches from the center of the shaft bearing, measured parallel to the shaft. The radius of crank arm is 10 inches. Assume S equal to 10,000. Calculate the diameter of the crank shaft.

8. On a short, vertical steel shaft the load is 5,000 pounds. A gear, 36 teeth, $1\frac{1}{2}$ diametral pitch, at top of shaft, transmits a load of 4,000 pounds at the pitch line. Safe shear $= 7{,}500$. What is the diameter of the shaft?

SPUR GEARS.

NOTATION—The following notation is used throughout the chapter on Spur Gears:

b = Breadth of rectangular section of arm (inches).

M, M_1 = Revolutions per minute.

μ = Coefficient of friction between teeth.

C = Width of arm extended to pitch line (inches).
c = Distance from neutral axis to outer fiber (inches).
D = Pitch diameter of gear (inches).
F = Face of gear (inches).
f = Clearance of tooth at bottom (inches).
G = Thickness of arm extended to pitch line (inches).
H = Thickness of tooth at any section (inches).
h = Depth of rectangular section of arm (inches).
I = Moment of inertia.
K = Thickness of rim (inches).
L = Distance from top of tooth to any section (inches).
N = Number of teeth.
n = Number of arms.
P = Diametral pitch (teeth per inch of diameter).
P^1 = Circular pitch (inches).
Q, Q_1 = Normal pressure between teeth (lbs.).
R, R_1 = Resultant pressure between teeth (lbs.).
r, r_1 = Radius of pitch circles (inches).
S = Fiber stress of material (lbs. per sq. in.).
s = Addendum of tooth (inches) = Dedendum of tooth.
t = Thickness of tooth at pitch line (inches).
W = Load at pitch line (lbs.).
y = Coefficient for "Lewis" formula.

ANALYSIS. If a cylinder be placed on a plane surface, with its axis parallel to the plane, an attempt to rotate the cylinder about its axis would cause it to roll on the plane.

Again, if two cylinders be provided with axial bearings, and be slightly pressed together, motion of one about its axis will cause a similar motion of the other, the two surfaces rolling one on the other at their common tangent line. If moved with care, there will be no slipping in either of the above cases—which is explained by the fact that no matter how smooth the surfaces may appear to be, there is still sufficient roughness to make the little irregularities interlock and act like minute teeth.

The magnitude of the force possible to be transmitted depends not only on the roughness of the surfaces, but on the amount of pressure between them. Suppose that one cylinder is a part of a hoisting drum, on which is wound a rope with a weight attached. We can readily make the weight so great that, no matter how hard we press the two cylinders together, the driving cylinder will not turn the hoisting cylinder, but will slip past it. If now, instead of increasing the pressure, which is detrimental both to cylinders and bearings of same, we increase the coarseness of the surfaces, or, in other words, put teeth of appreciable size on these surfaces, we attain the desired result of positively driving without excessive side pressure.

These artificial projections, or teeth, must fit into one another; hence the surfaces of the original cylinders, having been broken up into alternate projections and hollows, have entirely disappeared to the eye; they nevertheless exist as ideal or imaginary surfaces, which roll together with the same surface velocities as if in bodily form, provided that the curves of the teeth are correctly formed. Several mathematical curves are available for use as tooth outlines, but in practice the **involute** and **cycloidal curves** are the only ones used for this purpose.

The ideal surfaces are known as **pitch cylinders** or **pitch circles.** In Fig. 32 is shown an end view of such a pair of cylinders in contact at their pitch point P. In gear calculations we assume that there is no slip between the pitch circles, acting as driving cylinders; hence the speeds of the two pitch circles at the pitch point are equal. If M and M_1 be the revolutions per minute of the cylinders respectively, r and r_1 their radii, then

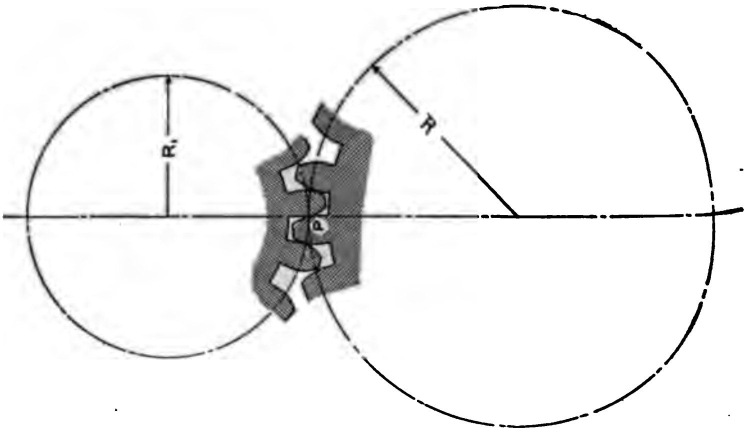


Fig. 32.

$$2\pi r M = 2\pi r_1 M_1;$$

or, $$\frac{M}{M_1} = \frac{r_1}{r}. \qquad (60)$$

That is, the number of revolutions varies inversely as the radii.

The simple calculation as above is the key to all calculations involving gear trains in reference to their speed ratio.

Fig. 33 represents cycloidal teeth in the two extreme positions of beginning and ending contact. The normal pressure Q or Q between the teeth in each position acts through the pitch point O as it must always do in order to insure the condition of ideal roll ing of the pitch circles, and the velocity ratio proportional to $\frac{r_1}{r}$ As the surfaces of the teeth slide together, frictional resistance is produced at their point of contact. This force is widely variable, depending on the material and condition of the tooth surfaces, whether smooth and well lubricated, or rough and gritty. As this resistance acts in conjunction with the normal force between the teeth, we may construct a parallelogram of forces on these two as a base, the resultant pressure between the teeth being slightly changed thereby, as shown in Fig 33.

Assuming a coefficient of friction μ, the force of friction is μ Q or μ Q_1 and the resultant pressure R or R_1.

Tooth B of the FOLLOWER is therefore under a heavy bending moment measured by the product RL, L being the perpendicular distance from the center of the tooth at its base to the line of the force. This tooth also has a relatively small compressive stress due to the resolved part of R along the radius, and a relatively small shearing stress due to the resolved part of R along a tangent to the pitch circle.

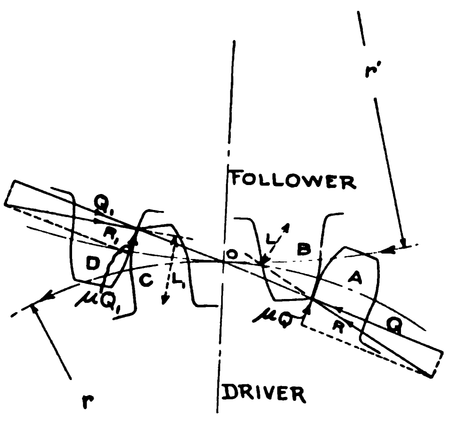


Fig. 33.

Tooth D of the driven wheel or FOLLOWER has a relatively large shearing stress, a small bending moment, and practically no direct compressive stress.

Tooth A of the driving wheel or DRIVER has a relatively large shearing stress, a small bending moment, and small compressive stress.

Tooth C of the DRIVER has a large bending moment, but small compressive and shearing stresses.

The conditions as noted above are not those of every pair of gears, in fact they vary with every difference of pitch circle, or of detail and position of tooth. It is true, however, that in nearly all cases in practice the bending stress is the controlling one from a theoretical standpoint. Moreover, the designer must consider the form and strength of the tooth when it is under the condition of maximum moment. This evidently, from the above, occurs at the beginning of contact, for the follower teeth; and at the end of contact, for the driver teeth. In the particular case illustrated in

Fig. 33, if the material in both gears were the same, tooth C, being the weaker at the root, would probably break before B; but if C were of steel, and B of cast iron, B might break first.

It will be noticed that R is nearly parallel to the top of the tooth; and it may easily happen that the friction may become of such a value that it will turn the direction of R until it lies along the top of the tooth exactly, which is the condition for maximum moment. For strength calculations it is usual to consider this condition as existing in all cases.

At the beginning of contact there is more or less shock when the teeth strike together, and this effect is much more evident at high speeds. There is also at the beginning of contact a sort of chattering action as the driving tooth rubs along the driven tooth.

Uniform distribution of pressure along the face of the tooth is often impaired by uneven wear of the bearings supporting the gear shafts, the pressure being localized on one corner of the tooth. The same effect is caused by the accidental presence of foreign material between the teeth. Again, in cast gearing, the spacing may be irregular, or, on account of draft on the pattern, the teeth may bear at the high points only. While it is usual to consider that the load is evenly distributed along the face of the tooth, yet the above considerations show that *an ample margin of strength must always be allowed* on account of these uncertainties.

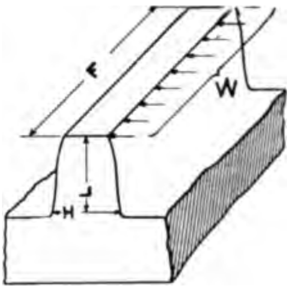


Fig. 34.

When the number of teeth in the mating gears is high, the load will be distributed between several teeth ; but, as it is almost certain that at some time the proper distribution of load will not exist, and that one tooth will receive the full load, it is considered that practically the only safe method is so to design the teeth that a single tooth may be relied upon to withstand the full load without failure.

THEORY. Based on the Analysis as given, the theory of gear teeth assumes that one tooth takes the whole load, and that this load is evenly distributed along the top of the tooth and acts parallel with its base, thus reducing the condition of the tooth to that of a cantilever beam. The magnitude of this load at the top of the tooth is taken for convenience the same as the force transmitted at the pitch circle. This condition is shown in Fig. 34. Equating the external moment to the internal moment, we then have, from mechanics:

$$WL = \frac{SI}{c} = \frac{SFH^2}{6}. \qquad (61)$$

The thickness H is usually taken either at the pitch line or at the root of the tooth just before the fillet begins; and L, of course, is dependent on the tooth dimensions. The formula is most readily used when the outline of the tooth is either assumed or known, a trial calculation being made to see if it will stand the load, and a series of subsequent calculations followed out in the same way until a suitable tooth is found. This method is pursued because there are certain even pitches which it is desirable to use; and it is safe to say that any calculation figured the reverse way would result in fractional pitches. The latter course may be used, however, and the nearest even pitch chosen as the proper one.

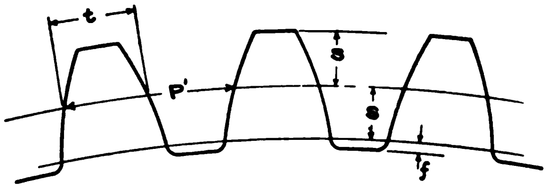
As stated under "Analysis," there are a great many circumstances attending the operation of gears which make impossible the purely theoretical application of the beam formulæ. For this reason there is no one element of machinery which depends so much on experience and judgment for correct proportion as the tooth of a gear. Hence it is true that a rational formula based on the theoretical one is really of the greater practical value in tooth design.

If we examine formula 61, we find that in a form solved for W, we have:

$$W = \frac{SFH^2}{6\,L}. \qquad (62)$$

Of these quantities, H and L are the only variables, for we can make the others what we choose. H and L depend upon the circular pitch P^1 and the curvature and outline of the tooth. If now we could settle on a standard system of teeth, we could establish a coefficient to be used to take the place of the variable part of H and L, which depends on the outline of tooth, and we should thus have an empirical formula which would be on a theoretical basis.

This, Mr. Wilfred Lewis has done; and it is safe to say that this formula is more universally used and with more satisfactory practical results than any other formula, theoretical or practical, that has ever been devised. His coefficient is known as y, and was determined from many actual drawings of different forms of teeth showing the weakest section. This coefficient is worked out for the three most common systems as follows:



$$t = \frac{P^1}{2} \qquad f = \frac{t}{10} \qquad s = \frac{P^1}{\pi}$$

Fig. 35.

$$\text{For } 20^\circ \text{ involute, } y = 0.154 - \frac{0.912}{N}. \qquad (63)$$

$$\text{For } 15^\circ \text{ involute and cycloidal, } y = 0.124 - \frac{0.684}{N}. \qquad (64)$$

$$\text{For radial flanks, } y = 0.075 - \frac{0.276}{N}. \qquad (65)$$

The tooth upon which the above is based is the American standard or Brown & Sharpe tooth, for which the proportions are shown in Fig. 35.

The "Lewis" formula* is:

$$W = SP^1 Fy. \qquad (66)$$

A table indicating the value of S for different speeds follows:

Safe Working Stresses for Different Speeds.

Speed of teeth, ft. per min.	100	200	300	600	900	1200	1800	2400
Cast iron	8000	6000	4800	4000	3000	2400	2000	1700
Steel	20000	15000	12000	10000	7500	6000	5000	4300

---

*Note. A full and convenient statement of the Lewis formula will be found in "Kent's Pocket Book."

A usual relation of F to P^1 is:

$$\text{For cast teeth, } F = 2P^1 \text{ to } 3P^1. \qquad (66)$$

$$\text{For cut teeth, } F = 3P^1 \text{ to } 4P^1. \qquad (67)$$

The usual method of handling these formulæ is as follows:

The pitch circles of the proposed gears are known or can be assumed; hence W can readily be figured, also the speed of the teeth, whence S can be read from the table. The desired relation of F to P^1 can be arbitrarily chosen, when P^1 and y become the only unknown quantities in the equation. A shrewd guess can be made for the number of teeth, and y calculated therefrom. Then solve the equation for P^1 which will undoubtedly be fractional. Choose the nearest even pitch, or, if it is desired to keep an even diametral pitch, the fractional pitch that will bring an even diametral pitch. Now, from this final and corrected pitch, and the diameter of the pitch circle, calculate the number of teeth N in the gear. Check the assumed value of y by this positive value of N.

Another good way of using this formula is to start with the pitch and face desired, and the diameter of the pitch circle. In this case W is the only unknown quantity, and when found can be compared with the load required to be carried. If too small, make another and successive calculations until the result approximates the required load.

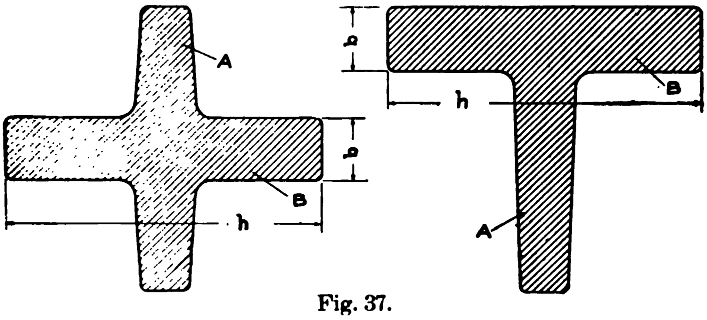


Fig. 37.

SPUR GEAR RIM, ARMS, AND HUB.

ANALYSIS and THEORY. The rim of a gear has to transmit the load on the teeth to the arms. It is thus in tension on one side of the teeth in action, and in compression on the other. The section of the rim, however, is so dependent on other practical considerations which call for an excess of strength in this respect, that it is not considered worth while to attempt a calculation on this basis.

Gears seldom run fast enough to make necessary a calculation for centrifugal force ; and in general it can be said that the design of the rim is entirely dependent on practical considerations. These will appear later under " Practical Modification. "

The arms of a gear are stressed the same as pulley arms, the same theory answering for both, except that a gear rim always being much heavier than a pulley rim, the distribution of load amongst the arms is better in the case of a gear than of a pulley, and it is usually safe to assume that each arm of a gear takes its full proportion of load ; or, for an oval section, equating the external moment to the internal moment as in the case of pulleys, we have :

$$\frac{WD}{n2} = 0.0393\, Sh^3. \qquad (68)$$

Heavy spur gears have the arms of a cross or T section (Fig. 37), the latter being especially applicable to the case of bevel gears where there is considerable side thrust. The simplest way of treating such sections is to consider that the whole bending moment is taken by the rectangular section whose greater dimension is in the direction of the load. The rest of the section, being close to the neutral axis of the section, is of little value in resisting the direct load, its function being to give sidewise stiffness. The equation for the cross or T style of arm, then is :

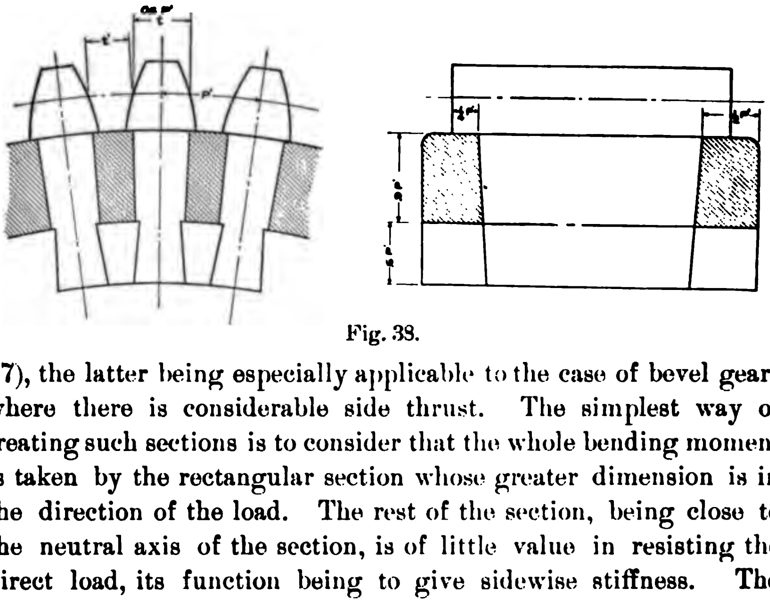


Fig. 38.

$$\frac{W}{n} \times \frac{D}{2} = \frac{Sbh^2}{6}. \qquad (69)$$

Either b or h may be assumed, and the other determined. As a guide to the section, b may be taken at about the thickness of the tooth.

Gear hubs are in no wise different from the hubs of pulleys or other rotating pieces. The depth necessary for providing sufficient strength over the key to avoid splitting is the guiding element, and can usually be best determined by careful judgment.

PRACTICAL MODIFICATION. The practical requirements, which no theory will satisfy, are many and varied. Sudden and severe shock, excessive wear due to an atmosphere of grit and corrosive elements, abrupt reversal of the mechanism, the throwing-in of clutches and pawls, the action of brakes—these and many other influences have an important bearing on gear design, but not one that can be calculated. The only method of procedure in such cases is to base the design on analysis and theory as previously given, and then add to the face of gear, thickness of tooth, or pitch an amount which judgment and experience dictate as sufficient.

Excessive noise and vibration are difficult to prevent at high speeds. At 1,000 feet per minute, gears are apt to run with an unpleasant amount of noise. At speeds beyond this, it is often necessary to provide **mortise teeth**, or teeth of hard wood set into a cast-iron rim (see Fig. 38). Rawhide pinions are useful in this regard. Fine pitches with a long face of tooth run much more smoothly at high speeds than a coarse pitch and narrow-faced tooth of equal strength. Greater care in alignment of shafts, however, is necessary, also stiffer supports.

Should it be impracticable to use a standard tooth of sufficient strength, there are several ways in which we can increase the carrying capacity without increasing the pitch. These are:

1. Use a stronger material, such as steel.
2. Shroud the teeth.
3. Use a hook tooth.
4. Use a stub tooth.

Shrouding a tooth consists in connecting the ends of the teeth with a rim of metal. When this rim is extended to the top of the tooth, the process is called "full-shrouding" (Fig. 39); and when carried only to the pitch line, it is termed "half-shrouding" (Fig. 40). The theoretical effect of shrouding is to make the tooth act like a short beam built in at the sides; and the tooth will practically have to be sheared out in order to fail. This modification of gear design requires the teeth to be cast, as the cutter cannot pass through the shrouding. The strength of the shrouded gear is estimated to be from 25 to 50 per cent above that of the plain-tooth type.

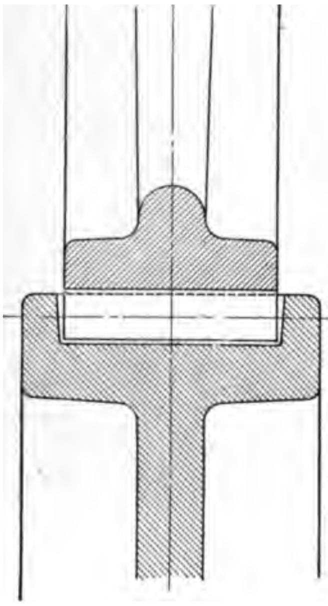


Fig. 39.

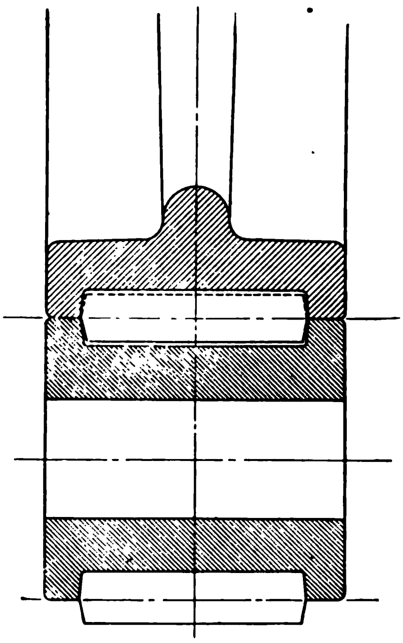


Fig. 40.

The **hook-tooth gear** (Fig. 41) is applicable only to cases where the load on the tooth does not reverse. The working side of the tooth is made of the usual standard curve, while the back is made of a curve of greater obliquity, resulting in a considerable increase of thickness at the root of the tooth. A comparison of strength between this form and the standard may be made by drawing the two teeth for a given pitch, measuring their thickness just at top of the fillet, and finding the relation of the squares of these dimensions. The truth of this relation is readily seen from an inspection of formula 61.

The **stub tooth** merely involves the shortening of the height of the tooth in order to reduce the lever arm on which the load acts, thus reducing the moment, and thereby permitting a greater load to be carried for the same stress.

The rim of a gear is dependent for its proportions chiefly on questions of practical moulding and machining. It must bear a certain relation to the teeth and arms, so that, when it is cooling in the mould, serious shrinkage stresses will not be set up, forming pockets and cracks. Moreover, when under pressure of the cutter in the producing of the teeth, it must not chatter or spring. This condition is quite well attained in ordinary gears when the thickness of the rim below the base of the tooth is made about the same as the thickness of the tooth.

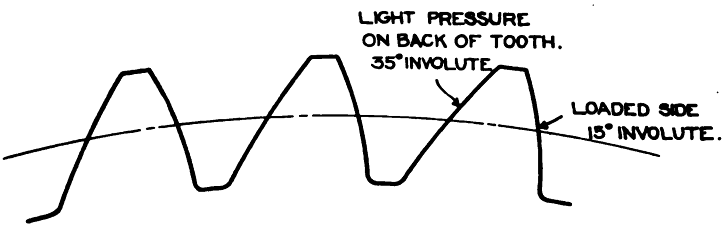


Fig. 41.

The stiffening ribs and arms must all be joined to the rim by ample fillets, and the cross-section must be as uniform as possible, to prevent unequal cooling and consequent pulling-away of the arms from the rim or hub. Often the calculated size of the arms at both rim and hub has to be modified considerably to meet this requirement.

The arms are usually tapered to suit the designer's eye, a small gear requiring more taper per foot than a large one. Both rim and hub should be tapered $\frac{1}{2}$ inch per foot to permit easy drawing-out from the mould.

The proportions given in the following table have been used with success as a basis of gear design in manufacturing practice. The table will serve as an excellent guide in laying out, and can be closely followed, in most cases with but slight modification. **Web gears** are introduced for small diameters where the arms begin to look awkward and clumsy.

Gear Design Data.

Measurements given in inches. Letters refer to Fig. 42.

Diametral pitch ..	P	$1\frac{1}{2}$	$1\frac{3}{4}$	2	$2\frac{1}{2}$	3	$3\frac{1}{2}$	4	5	6	8
Face............	F	$6\frac{1}{4}$	$5\frac{1}{2}$	$4\frac{3}{4}$	$3\frac{3}{4}$	$3\frac{1}{4}$	$2\frac{3}{4}$	$2\frac{1}{2}$	$2\frac{1}{8}$	$1\frac{7}{8}$	$1\frac{1}{2}$
Thickness of arm when extended to pitch line....	G	$1\frac{3}{8}$	$1\frac{1}{4}$	$1\frac{1}{8}$	1	$\frac{7}{8}$	$\frac{13}{16}$	$\frac{3}{4}$	$\frac{11}{16}$	$\frac{5}{8}$	$\frac{1}{2}$
Width of arm when extended to pitch line	C	4	$3\frac{1}{2}$	3	$2\frac{1}{2}$	$2\frac{1}{4}$	2	$1\frac{3}{4}$	$1\frac{1}{2}$	$1\frac{3}{8}$	$1\frac{1}{8}$
Thickness of rim..	K	$2\frac{3}{4}$	$2\frac{3}{8}$	$2\frac{1}{8}$	$1\frac{3}{4}$	$1\frac{1}{2}$	$1\frac{3}{8}$	$1\frac{1}{4}$	1	$\frac{7}{8}$	$\frac{3}{4}$
Depth of rib......	E	2	$1\frac{3}{4}$	$1\frac{1}{2}$	$1\frac{1}{4}$	1	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$
Thickness of web.	T	$1\frac{1}{8}$	1	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{9}{16}$	$\frac{1}{2}$	$\frac{7}{16}$	$\frac{3}{8}$	$\frac{5}{16}$

Number of arms, 6.
Give inside of rims and hub a draft of $\frac{1}{2}$ inch per foot.

BEVEL GEARS.

NOTATION—The following notation is used throughout the chapter on Bevel Gears:

A = Apex distance at pitch element of cone (inches).
A¹= Apex distance at bottom element of tooth (inches).
B = Angle of bottom of tooth (degrees).
C = Pitch angle (degrees).
D = Pitch diameter (inches).
E = Radius increment of gear (inches).
F = Face of gear (inches).
f = Clearance at bottom (inches).
G = Angle of face (degrees).
H = Cutting angle (degrees).
K = Radius increment of pinion (inches).
N = Number of teeth.
N¹= Formative number of teeth, or the number corresponding to the spur gear on which the outline of tooth is made.
O D= Outside diameter (inches).
P = Diametral pitch related to pitch diameter (teeth per inch).
P¹ = Circular pitch measured on the circumference of D (inches).
S = Working strength of material (lbs. per sq. in.).
s = Addendum, or height of tooth above pitch line (inches).
$s+f$= Depth of tooth below pitch line (inches).
T = Angle of top of tooth (degrees).
t = Thickness of tooth at pitch line (inches).
W = Working load at pitch line (lbs.).
y = Factor in "Lewis" formula.

ANALYSIS. It is possible to consider bevel gears as the general case of which spur gears are a special form. The pitch surfaces of spur gears described above as cylinders, mathematically considered, are cones whose vertices are infinitely distant, while bevel gears likewise are based on pitch cones, but with a vertex at some finite point, common to the mating pair. Hence, as we might expect, the laws of tooth action are similar in bevel gears to those in the case of spur gears. The profile of the tooth in the former case, however, is based, not on the real radius of the pitch cone, but on the radius of the normal cone; and in the development of the outline the latter is treated just as though it were the radius of a spur gear. The tooth thus formed is wrapped back upon the normal cone face, and becomes the large end of the tapering bevel-gear tooth (see Fig. 44).

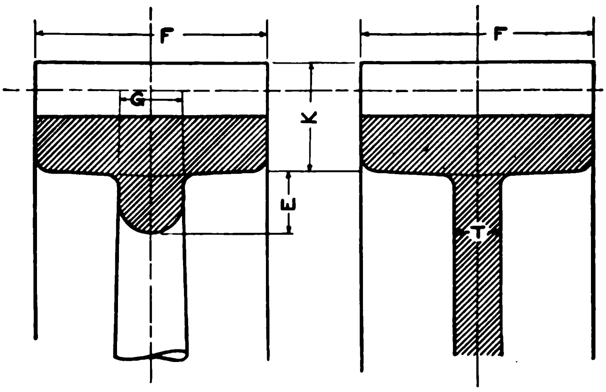


Fig. 42.

The teeth of bevel gears, being simply projections with bases on the pitch cones, have a varying cross-section decreasing toward the vertex; also a trapezoidal section of root, the latter section acting as a beam section to resist the cantilever moment due to the tooth load.

The arms must, as in the case of spur gears, transmit the load from the tooth to the shaft; in addition, the arms of a bevel gear are subjected to a side thrust due to the wedging action of the cones. Hence sidewise stiffness of the arms is more essential in this type of gear than in the case of the spur gear.

THEORY. It is evident that the calculation of tooth strength based on a trapezoidal section of root would be somewhat compli-

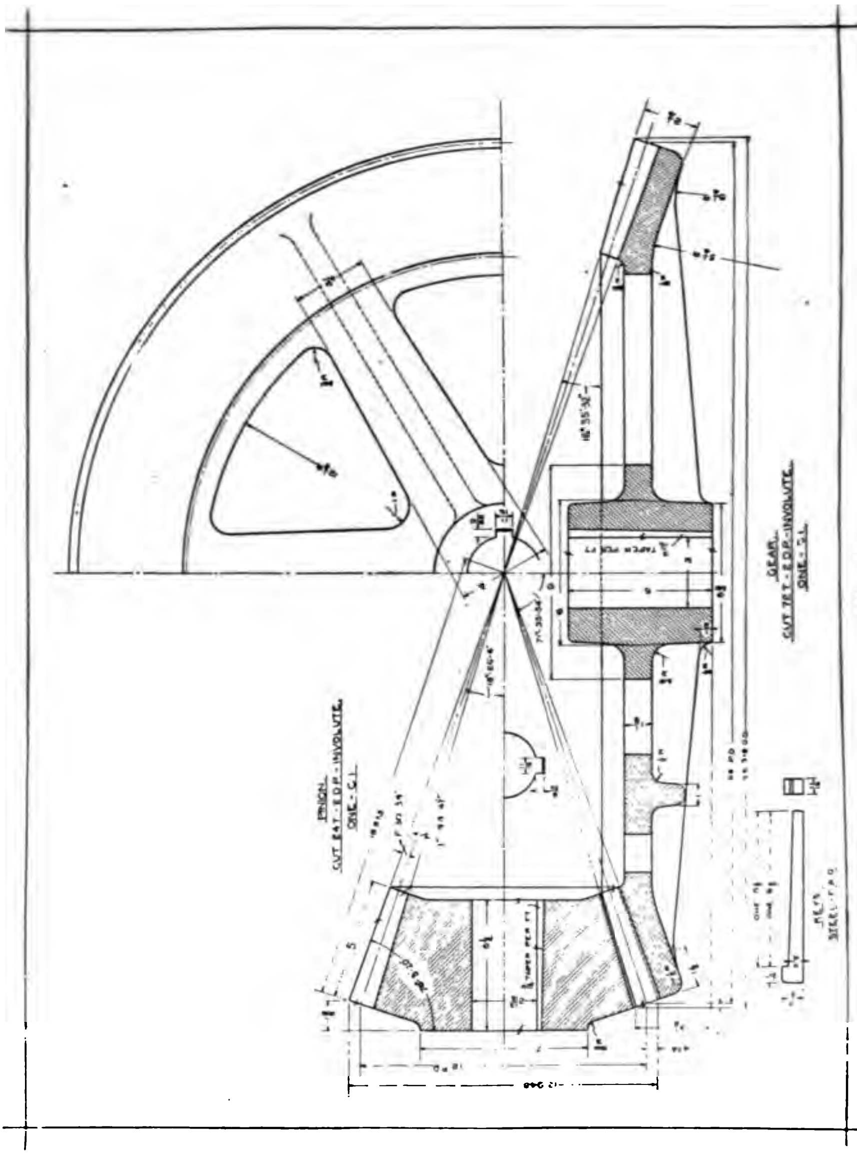


Fig. 43.

cated; also that the trapezoid in most cases would be but little different from a true rectangle. Hence the error will be but slight if the average cross-section of the tooth be taken to represent its strength, and the calculation made accordingly.

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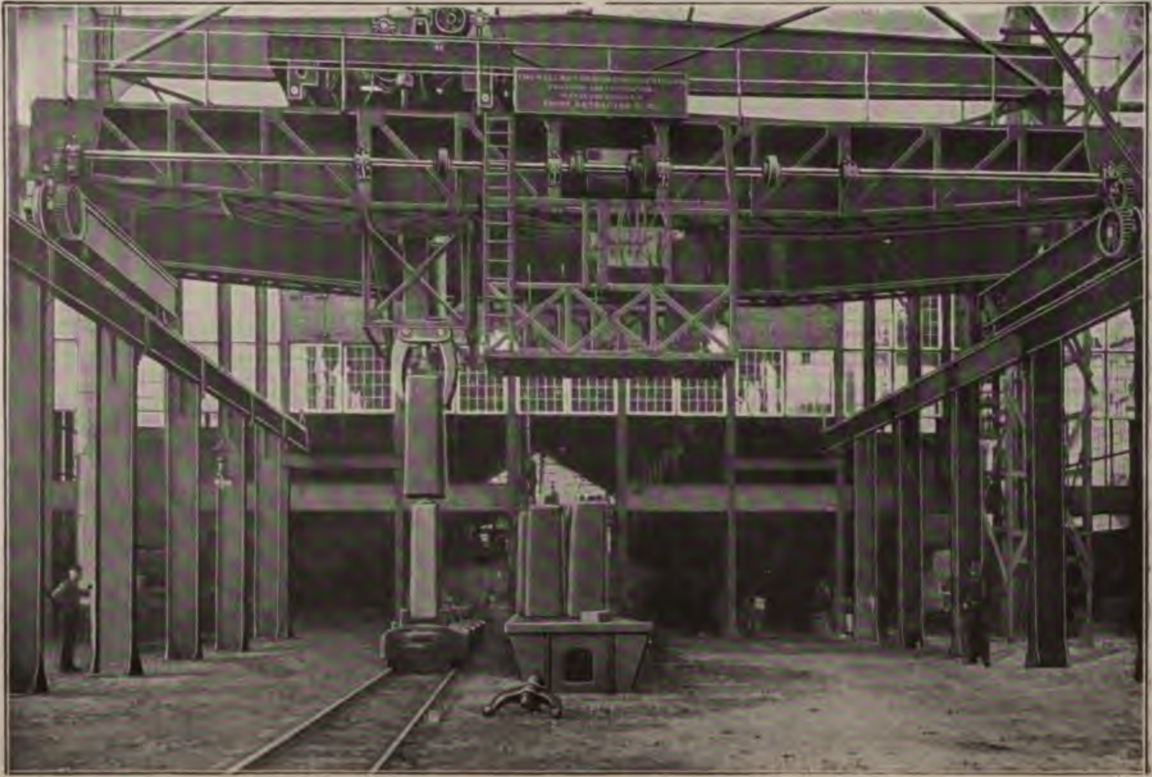


ELECTRIC INGOT STRIPPER.
The Wellman-Seaver-Morgan Co.

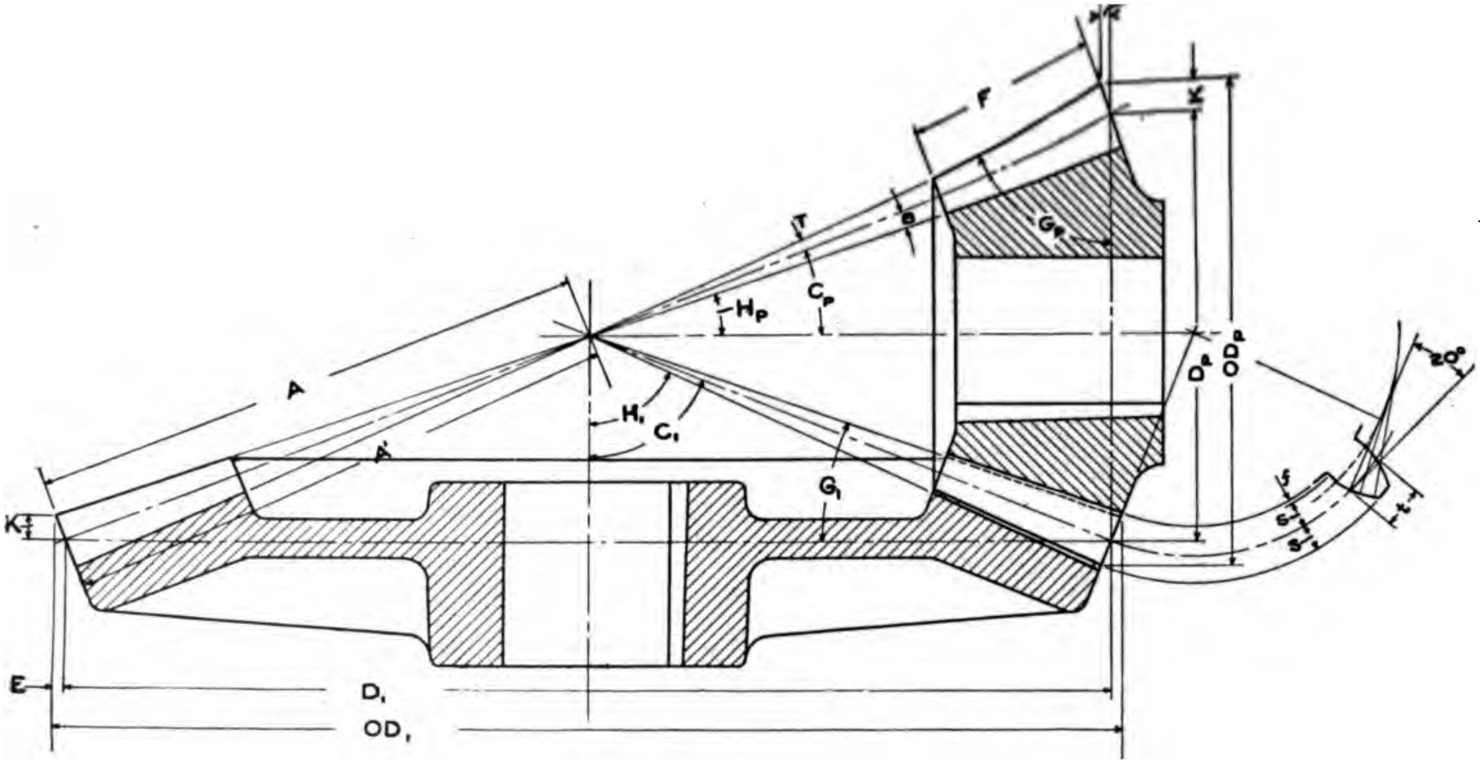


Fig. 44.

Fig. 45 shows a bevel-gear tooth with the average cross-section in dotted lines. For the purpose of calculation, the assumption is made that the section A is carried the full length of the face of the gear, and that the load which this average tooth must carry is the calculated load at the pitch line of section A. This is equivalent to saying that the strength of a bevel-gear tooth is equal to that of a spur-gear tooth which has the same face, and a section identical with that cut out by a plane at the middle of the bevel tooth. The load, as in the case of the spur gear, should be taken at the top of the tooth; and its magnitude can be conveniently calculated at the mean pitch radius of the bevel face, without appreciable error.

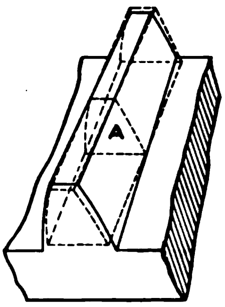


Fig. 45.

This similarity to spur gears being borne in mind, the calculation for strength needs no further treatment. Once the average tooth is assumed or found by layout, a strict following-out of the methods pursued for spur-gear teeth will bring consistent results.

The detail design of a pair of bevel gears involves some trigonometrical computations in order properly to dimension the drawing for use in finishing the blanks and subsequently in cutting the teeth, or, in the case of cast gears, in making the pattern. These calculations, although simple, are yet apt to be tedious; and inaccuracies are likely to creep in if a definite system of relations be not maintained. Hence the results of these calculations are given below in condensed and reduced form. The deduction of these formulæ is a simple and interesting exercise in trigonometry; and it is urged that they be worked out by the student from the figure, in which case he will feel greater confidence in their use.

Axes of Gears at 90 Degrees.

Use subscript 1 for gear; P for pinion. Letters refer to Fig. 44.

$$P = \frac{N}{D} = \frac{\pi}{P'}. \qquad (70)$$

$$s = \frac{1}{P} = \frac{P'}{\pi}. \qquad (71)$$

$$t = \frac{P'}{2} = \frac{\pi}{2P}. \qquad (72)$$

$$f = \frac{t}{10} = \frac{P^1}{20} = \frac{\pi}{20P}. \tag{73}$$

$$\tan C_p = \frac{N_p}{N_1};\ \tan C_1 = \frac{N_1}{N_p}. \tag{74}$$

$$\tan T = \frac{s}{A} = \frac{2 \sin C}{N}. \tag{75}$$

$$\tan B = \frac{s + f}{A} = \frac{2.314 \sin C}{N}. \tag{76}$$

$$s + f = A \tan B = \frac{1.157}{P} = 0.368P^1. \tag{77}$$

$$A = \frac{N}{2P \sin C} = \frac{1}{2P} \sqrt{N_1^2 + N_p^2} = \frac{1}{2} \sqrt{D_1^2 + D_p^2}. \tag{78}$$

$$A^1 = \frac{A}{\cos B} = \frac{N}{2P \cos B \sin C}. \tag{79}$$

$$G_1 = 90^\circ - (C_1 + T);\ G_p = 90^\circ - (C_p + T). \tag{80}$$

$$E = S \cos C_1 = S \sin C_p. \tag{81}$$

$$K = S \cos C_p = S \sin C_1. \tag{82}$$

PRACTICAL MODIFICATION. The practical requirements to be met in transmission of power by bevel gears are the same as for spur gears; but in the case of bevel gears even greater care is necessary to provide stiffness, strength, true alignment, and rigid supports. As far as the gears themselves are concerned, a long face is desirable; but it is much more difficult to gain the advantage of its strength than in the case of spur gears, because full bearing along the length of the tooth is hard to guarantee.

The rim usually requires a series of ribs running to the hub to give required stiffness and strength against the side thrust which is always present in a pair of bevel gears. Instead of arms, the tendency of bevel-gear design, except for very large gears, is toward a web on account of the better and more uniform connection thereby secured between rim and hub. This web may be lightened by a number of holes, so that the resultant effect is that of a number of wide and flat arms.

The hubs naturally have to be fully as long as those of spur gears, because there is greater tendency to rock on the shaft, due to the side thrust from the teeth, mentioned above.

The teeth on small gears are cut with rotary cutters, at least two finishing cuts being necessary, one for each side of the tapering tooth. The more accurate method is to plane the teeth on a special gear planer, and this method is followed on all gears of any considerable size. The practical requirement here is that no portion of the hub shall project so as to interfere with the stroke curved to embrace the worm, but are twisted across the face of the gear, so that it would be practically impossible to devise a purely theoretical method of exact calculation. The most reasonable thing to do is to assume the teeth as being equally as strong as spur-gear teeth of the same circular pitch, and to figure them accordingly. It is probably true, however, that the load is carried by more than one tooth, especially in a hobbed wheel; so we shall be safe in assuming that two—and, in case of large wheels, three—teeth divide the load between them. With these considerations borne in mind, the case reduces itself to that of a simple spur-gear tooth calculation, which has already been explained under the heading "Spur Gears."

The worm teeth, or threads, are probably always stronger than the worm-gear teeth; so no calculation for their strength need be made.

The twisting moment on the worm shaft is not determined so directly as in the case of spur gears. The relative number of revolutions of the two shafts depends upon the "lead" of the worm thread and the number of teeth in the gear.

Lead (L) is the distance parallel to the axis of the worm which any point in the thread advances in one revolution of the worm. **Pitch** (P^1) is the distance parallel to the axis of the worm between corresponding points on adjacent threads. The distinction between lead and pitch should be carefully observed, as the two are often confounded, one with the other.

The thread may be single, double, triple, etc., the index of the thread i, being 1, 2, 3, etc., in accordance therewith. The relation between lead and pitch may then be expressed by an equation, thus:

$$L = i\,P^1. \qquad (84)$$

When the index of the thread is changed the speed ratio is changed, the relation being shown by the equation:

$$\frac{M}{M_w} = \frac{i}{N} \qquad (85)$$

If the efficiency were 100 per cent between the two shafts, the twisting moments would be inversely as the ratio of the speeds thus:

$$\frac{T_w}{T} = \frac{M}{M_w} = \frac{i}{N};$$

or,
$$T_w = \frac{Ti}{N}; \tag{86}$$

but for an efficiency E the equation would be:

$$\frac{T_w}{T} = \frac{i}{EN};$$

or,
$$T_w = \frac{Ti}{EN}. \tag{87}$$

The diameter of the worm is arbitrary. Change of this diameter has no effect on the speed ratio. It has a slight effect on the efficiency, the smaller worm giving a little higher efficiency. The diameter of the worm runs ordinarily from 3 to 10 times the circular pitch, an average value being $4P^1$ or $5P^1$.

A longitudinal cross-section through the axis of the worm cuts out a rack tooth, and this tooth section is usually made of the standard $14\frac{1}{2}°$ involute form shown in Fig. 46 for a rack.

The end thrust, of a magnitude practically equal to the pressure between the teeth, has to be taken by the hub of the worm against the face of the shaft bearing. A serious loss of efficiency from friction is likely to occur here. This is often reduced, however, by roller or ball bearings. With two worms on the same shaft, each driving into a separate worm gear, it is possible to make one of the worms right-hand thread, and the other left-hand, in which case the thrust is self-contained in the shaft itself, and there is absolutely no end thrust against the face of the bearing. This involves a double outfit throughout, and is not always practicable.

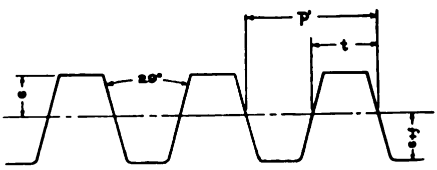


Fig. 46.

There are few mathematical equations necessary for the dimensioning of a worm and worm gear. The formulæ for the tooth parts as given on page 120 apply equally well in this case.

PRACTICAL MODIFICATION. The discussion of the efficiency E of the worm and worm gear is more of a practical than of a theoretical nature. It seems to be true from actual operation, as well as theory, that the steeper the threads the higher the efficiency. In actual practice we seldom have opportunity to change the slope of the thread to get increased efficiency. The slope is usually settled from considerations of speed ratio, or available space, or some other condition. The usual practical problem is to take a given worm and worm gear, and to make out of it as efficient a device as possible. With hobbed gears running in oil baths, and with moderate pressures and speeds, the efficiency will range between 40 per cent and 70 per cent. The latter figure is higher than is usually attained.

To avoid cutting and to secure high efficiency, it seems essential to make the worm and the gear of different materials. The worm-thread surfaces being in contact a greater number of times than the gear teeth, should evidently be of the harder material. Hence we usually find the worm of steel, and the gear of cast iron, brass, or bronze. To save the expense of a large and heavy bronze gear, it is common to make a cast-iron center and bolt a bronze rim to it.

The worm, being the most liable to replacement from wear, it is desirable so to arrange its shaft fastening and general accessibility that it may be readily removed without disturbing the worm gear.

The circular pitch of the gear and the pitch of the worm thread must be the same, and the practical question comes in as to the threads per inch possible to be cut in the lathe in the production of the worm thread. The pitch must satisfy this requirement; hence the pitch will usually be fractional, and the diameter of the worm gear, to give the necessary number of teeth, must be brought to it. While it would perhaps be desirable to keep an even diametral pitch for the worm gear, yet it would be poor design to specify a worm thread which could not be cut in a lathe.

The standard involute of $14\frac{1}{2}°$, and the standard proportions of teeth as given on page 120 are usually used for worm threads. This system requires the gear to have at least 30 teeth, for if fewer teeth are used the thread of the worm will interfere with the flanks of the gear teeth. This is a mathematical relation, and there are methods of preventing it by change of tooth proportions or of angle of worm thread; but there are few instances in which less than 30 teeth are required, and it is not deemed worth while to go into a lengthy discussion of this point.

The angle of the worm embraced by the worm-gear teeth varies from 60° to 90°, and the general dimensions of rim are made about the same as for spur gears. The arms, or the web, have the same reasons for their size and shape. Probably web gears and cross-shaped arms are more common than oval or elliptical sections.

Worm gears sometimes have cast teeth, but they are for the roughest service only, and give but a point bearing at the middle of the tooth. An accurately hobbed worm gear will give a bearing clear across the face of the tooth, and, if properly set up and cared for, makes a good mechanical device although admittedly of somewhat low efficiency.

Fig. 47 shows a detail drawing of a standard worm and worm gear. It should serve as a suggestion in design, and an illustration of the shop dimensions required for its production.

PROBLEMS ON SPUR, BEVEL, AND WORM GEARS.

1. Calculate proportions of a standard Brown & Sharpe gear tooth of 1½ diametral pitch, making a rough sketch and putting the dimensions on it.

2. Suppose the above tooth to be loaded at the top with 5,000 lbs. If the face be 6 inches, calculate the fiber stress at the pitch line, due to bending.

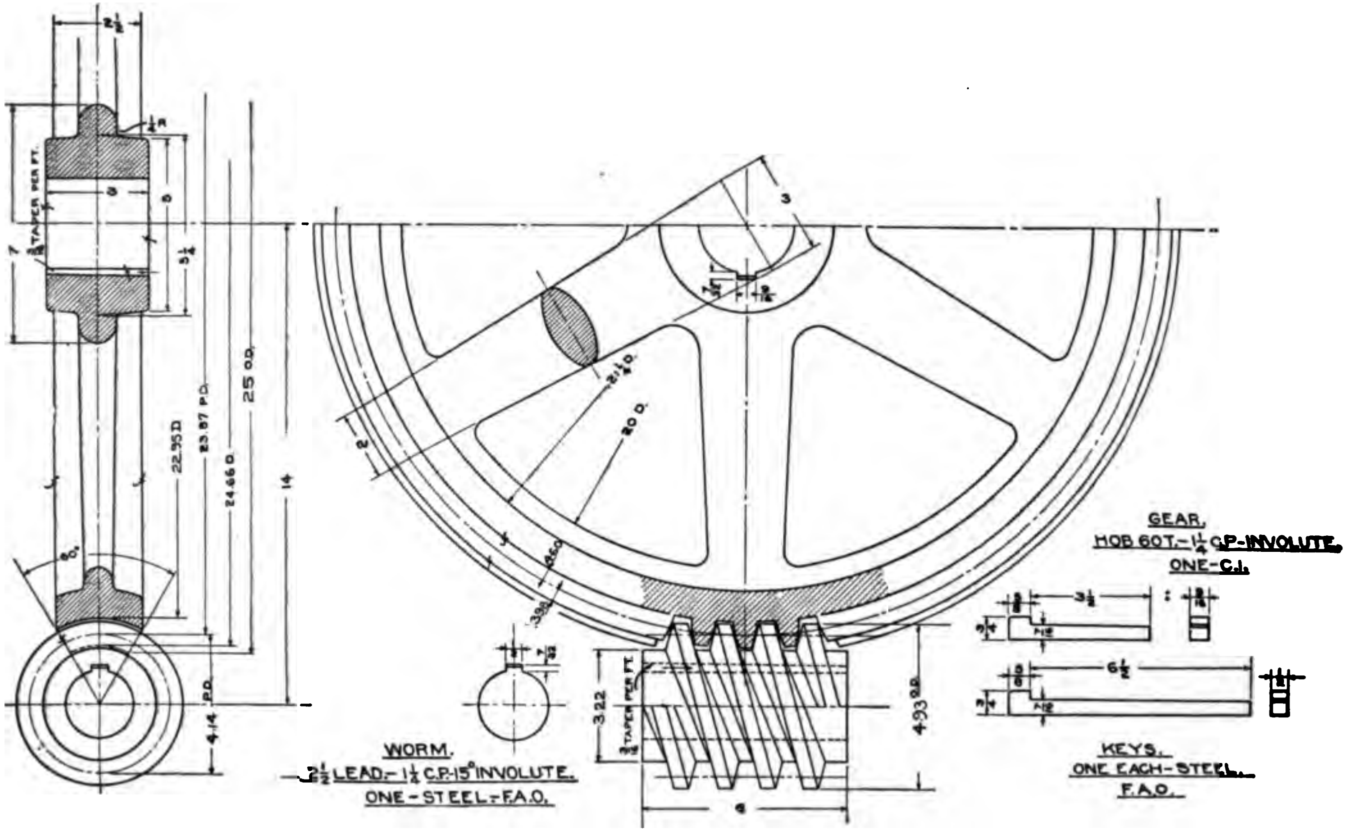
3. A tooth load of 1,200 lbs. is transmitted between two spur gears of 12-inch and 30-inch diameter, the latter gear making 100 revolutions per minute. Calculate a suitable pitch and face of tooth by the "Lewis" formula.

4. Assuming a ½-inch web on the 12-inch gear, calculate the shearing fiber stress at the outside of a hub 4 inches in diameter

5. Design elliptical arms for the 30-inch gear, allowing $S = 2,200$.

6. Design cross-shaped arms for 30-inch gear.

7. Calculate the dimensions shown in formulæ 70 to 82 inclusive for a pair of bevel gears of 20 and 60 teeth respectively, 2 diametral pitch, and 4-inch face. (The use of logarithmic tables makes the calculation much easier than with the natural functions.)



SECTION AND ELEVATION OF WORM GEAR.
Fig. 47

8. A worm wheel has 40 teeth, 3 diametral pitch, and double thread. Calculate (*a*) its lead; (*b*) its pitch diameter.

FRICTION CLUTCHES.

NOTATION—The following notation is used throughout the chapter on Friction Clutches:.

a =Angle between clutch face and axis of shaft (degrees)
H =Horse-power (33,000 ft.-lbs. per minute).
μ =Coefficient of friction (per cent).
N =Number of revolutions per minute.
P =Force to hold clutch in gear to produce W (lbs.).
R =Mean radius of friction surface (inches).
T =Twisting moment about shaft axis (inch-lbs.).
V =Force normal to clutch face (lbs.).
W =Load at mean radius of friction surface (lbs.).

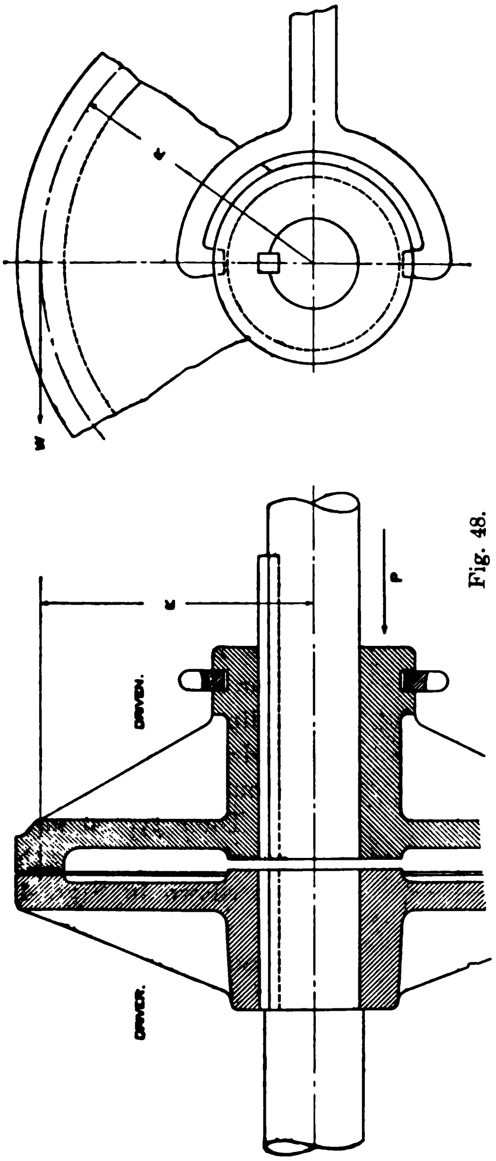


Fig. 48.

ANALYSIS. The friction clutch is a device for connecting at will two separate pieces of shaft, transmitting an amount of power between them to the capacity of the clutch. The connection is usually accomplished while the driving shaft is under full speed, the slipping between the surfaces which occurs during the throwing-in of the clutch, permitting the driven shaft to pick up the speed of the other gradually, without appreciable shock. The disconnection is made in the same manner, the amount of slipping which occurs depending on the suddenness with which the clutch is thrown out.

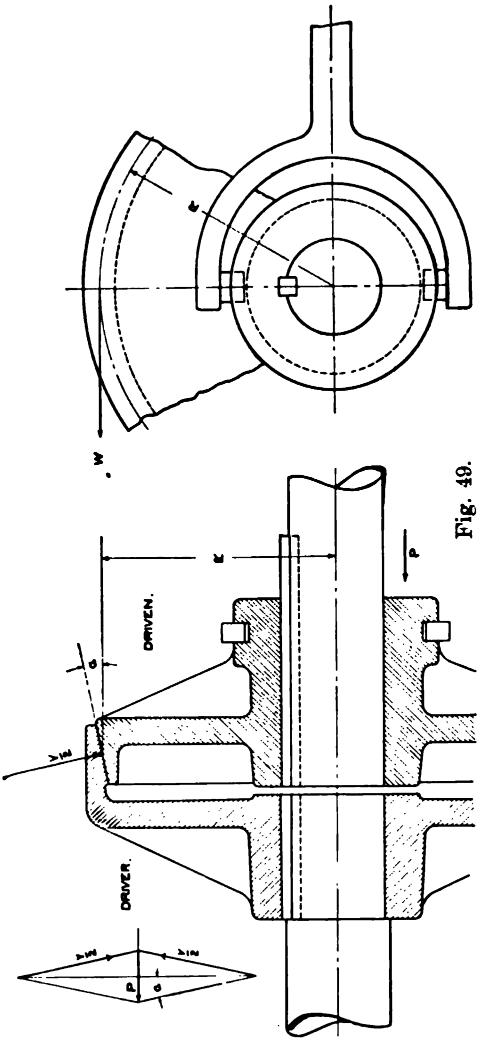


Fig. 49.

The force of friction is the sole driving element, hence the problem is to secure as large a force of friction as possible. But friction cannot be secured without a heavy normal pressure between surfaces having a high coefficient of friction between them. The many varieties of friction clutches which are on the market or designed for some special purpose, are all devices for accomplishing one and the same effect, *viz.*, the production of a heavy normal force or pressure between surfaces at such a radius from the driven axis, that the product of the force of friction thereby created and the radius shall equal the desired twisting moment about that axis.

Three typical methods of accomplishing this are shown in Figs. 48, 49, and 50. None of these drawings is worked out in operative detail. They are merely illustrations of principle, and are drawn in the simplest form for that purpose.

In Fig. 48 the normal pressure is created in the simplest possible way, an absolutely direct push being exerted between the discs, due to the thrust P of the clutch fork.

In Fig. 49 advantage is taken of the wedge action of the inclined faces, the result being that it takes less thrust P to produce the required normal pressure at the radius R.

In Fig. 50 the inclination of the faces is carried so far that the angle *a* of Fig. 49 has become zero; and by the toggle-joint action of the link pivoted to the clutch collar, the normal force produced may be very great for a slight thrust P. By careful adjustment of the length of the link so that the jaw takes hold of the clutch surface, when the link stands nearly vertical, a very easy operating device is secured, and the thrust P is made a minimum.

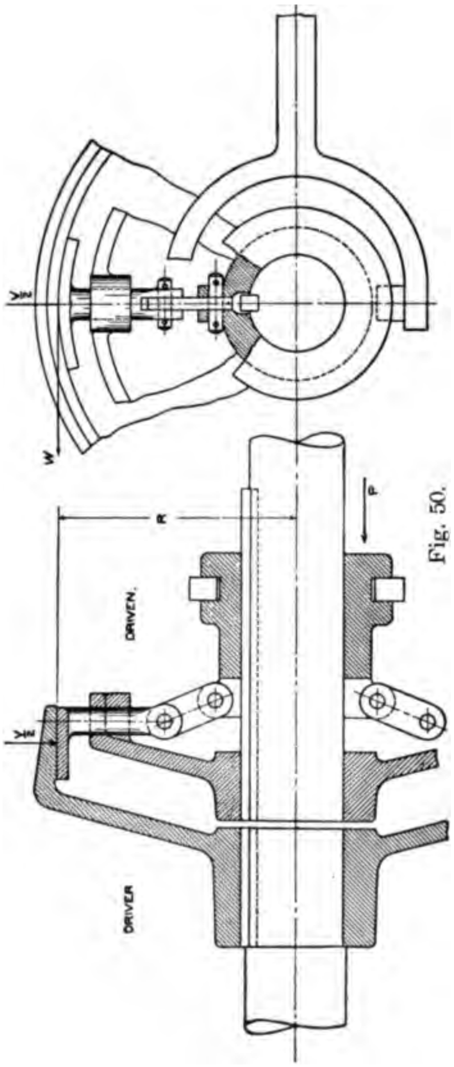


Fig. 50.

THEORY. Referring to Fig. 48 in order to calculate the twisting moment, we must remember that the force of friction between two surfaces is equal to the normal pressure times the coefficient of friction. This, in the form of an equation, using the symbols of the figure, is:

$$W = \mu P. \qquad (88)$$

Hence we may consider that we have a force of magnitude μP acting at the mean radius R of the clutch surface. The twisting moment will then be:

$$T = WR = \mu PR. \qquad (89)$$

Referring to equation 54, which gives twisting moment in terms of horse-power, and putting the two expressions equal to each other, we have:

$$T = \frac{63{,}025H}{N} = \mu PR;$$

or,

$$H = \frac{\mu NPR}{63{,}025}. \qquad (90)$$

This expression gives at once the horse-power that the clutch will transmit with a given end thrust P.

In Fig. 49 the equilibrium of the forces is shown in the little sketch at the left of the figure. The clutch faces are supposed to be in gear, and the extra force necessary to slide the two together is not considered, as it is of small importance. The static equations then are:

$$P = 2\frac{V}{2}\sin a;$$

or,

$$V = P \operatorname{cosec} a. \qquad (91)$$

$$W = \mu V = \mu P \operatorname{cosec} a. \qquad (92)$$

$$T = WR = \mu PR \operatorname{cosec} a. \qquad (93)$$

$$T = \frac{63{,}025H}{N} = \mu PR \operatorname{cosec} a;$$

or,

$$H = \frac{\mu NPR \operatorname{cosec} a}{63{,}025}. \qquad (94)$$

In Fig. 50, P would of course be variable, depending on the inclination of the little link. The amount of horse-power which this clutch would transmit would be the same as in the case of the device illustrated in Fig. 49, for an equal normal force V produced.

The further theoretical design of such clutches should be in accordance with the same principles as for arms and webs of pulleys, gears, etc. The length of the hubs must be liberal in order to prevent tipping on the shaft as a result of uneven wear. The end thrust is apt to be considerable; and extra side stiffness must be provided, as well as a rim that will not spring under the radial pressure.

PRACTICAL MODIFICATION. It is desirable to make the most complicated part of a friction clutch the driven part, for then the mechanism requiring the closest attention and adjustment may be brought to and kept at rest when no transmission of power is desired.

Simplicity is an important practical requirement in clutches. The wearing surfaces are subjected to severe usage; and it is essential that they be made not only strong in the first place, but also capable of being readily replaced when worn out, as they are sure to be after some service.

The form of clutch shown in Fig. 50 is the most efficient form of the three shown, although its commercial design is considerably different from that indicated. Usually the jaws grip both sides of the rim, pinching it between them. This relieves the clutch rim of the radial unbalanced thrust.

Adjusting screws must be provided for taking up the wear, and lock nuts for maintaining their position.

Theoretically, the rubbing surfaces should be of those materials whose coefficient of friction is the highest; but the practical question of wear comes in, and hence we usually find both surfaces of metal, cast iron being most common. For metal on metal the coefficient of friction μ cannot be safely assumed at more than 15 per cent, because the surfaces are sure to get oily.

A leather facing on one of the surfaces gives good results as to coefficient of friction, μ having a value, even for oily leather, of 20 per cent. Much slipping, however, is apt to burn the leather; and this is most likely to occur at high speeds.

Wood on cast iron gives a little higher coefficient of friction for an oily surface than metal on metal. Wood blocks can be so set into the face of the jaws as to be readily replaced when worn, and in such case make an excellent facing.

The angle a of a cone friction clutch of the type shown in Fig. 49, may evidently be made so small that the two parts will wedge together tightly with a very slight pressure P; or it may

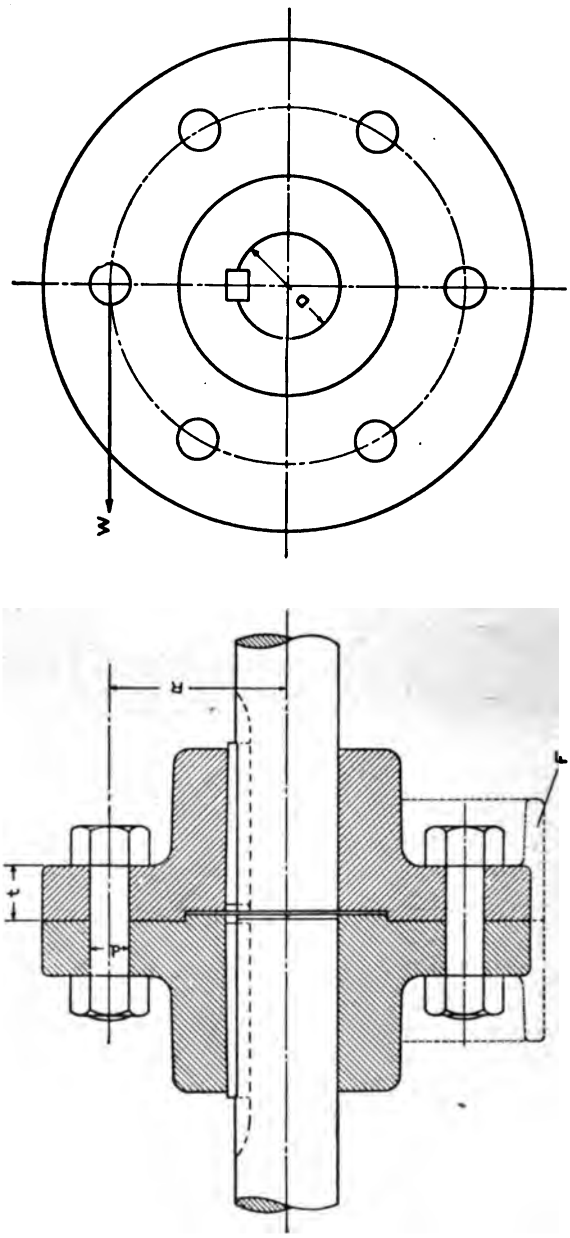
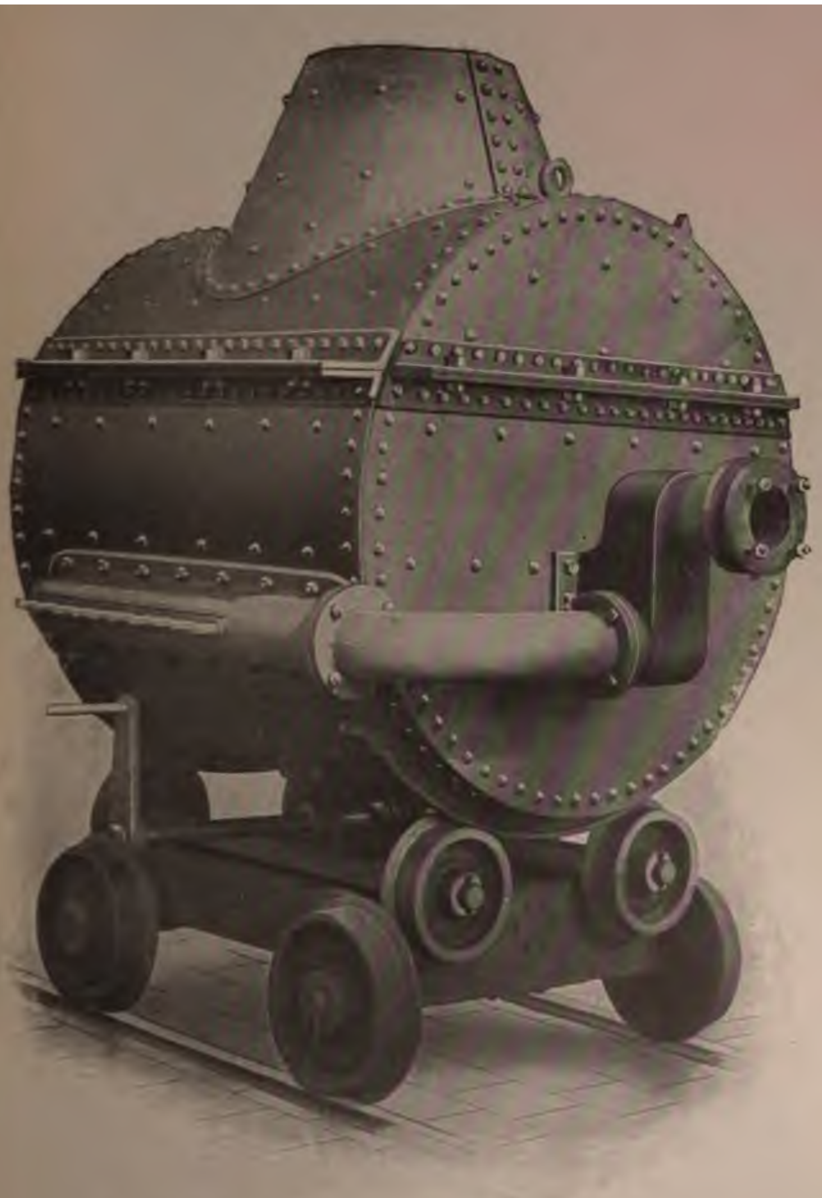


Fig. 51.



SMALL CYLINDRICAL CONVERTER. For Copper Matte.
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be so large as to have little wedging action, and approach the condition illustrated in Fig. 48. Between these limits there is a practical value which neither gives a wedging action so great as to make the surfaces difficult to pull apart, nor, on the other hand, requires an objectionable end thrust along the shaft in order to make the clutch drive properly.

For a = about 15°, the surfaces will free themselves when P is relieved.
" a = " 12°, " " require slight pull to be freed.
" a = " 10°, " " cannot be freed by direct pull of the hand, but require some leverage to produce the necessary force P.

PROBLEMS ON FRICTION CLUTCHES.

1. With what force must we hold a friction clutch in to transmit 30 horse-power at 200 revolutions per minute, assuming working radius of clutch to be 12 inches; coefficient of friction 15 per cent; angle a = 10° ?

2. How much horse-power could be transmitted, other conditions remaining the same, if the working radius were increased to 18 inches ?

3. What force would be necessary in problem 1, if the angle a were 15°, other conditions remaining the same ?

COUPLINGS.

NOTATION.—The following notation is used throughout the chapter on Couplings:

D = Diameter of shaft (inches).
d = Diameter of bolt body (inches).
n = Number of bolts.
R = Radius of bolt circle (inches).
S = Safe shearing fiber stress (lbs. per sq. in.).
S^c = Safe crushing fiber stress (lbs. per sq. in.).
T = Twisting moment (inch-lbs.).
t = Thickness of flange (inches).
W = Load on bolts (lbs.).

ANALYSIS. Rigid couplings are intended to make the shafts which they connect act as a solid, continuous shaft. In order that the shaft may be worked up to its full strength capacity, the coupling must be as strong in all respects as the shaft, or, in other words, it must transmit the same torsional moment. In the analysis of the forces which come upon these couplings, it is not considered that they are to take any side load, but that they are to act purely as torsional elements. It is doubtless true that in many cases they do have to provide some side strength and stiffness, but this is not their natural function, nor the one upon which their design is based.

Referring to Fig. 51, which is the type most convenient for analysis, we have an example of the simplest form of **flange coupling.** It consists merely of hubs keyed to the two portions, with flanges driving through shear on a series of bolts arranged concentrically about the shaft. The hubs, keys, and flanges are subject to the same conditions of design as the hubs, keys, and web of a gear or pulley, the key tending to shear and be crushed in the hub and shaft, and the hub tending to be torn or sheared from the flange. The driving bolts, which must be carefully fitted in reamed holes, are subject to a purely shearing stress over their full area at the joint, and at the same time tend to crush the metal in the flange, against which they bear, over their projected area. This latter stress is seldom of importance, the thickness of the flange, for practical reasons, being sufficient to make the crushing stress very low.

THEORY. The theory of hubs, keys, and flanges, being like that already given for pulleys and gears, need not be repeated for couplings. The shearing stress on the bolts is the only new point to be studied.

In Fig. 51, for a twisting moment on the shaft of T, the load at the bolt circle is $W = \frac{T}{R}$. If the number of bolts be n, equating the external force to the internal strength, we have:

$$W = \frac{T}{R} = \frac{S\pi d^2}{4} n. \qquad (95)$$

Although the crushing will seldom be of importance, yet for the sake of completeness its equation is given, thus:

$$W = \frac{T}{R} = S_c d t n. \qquad (96)$$

The internal moment of resistance of the shaft is $\frac{SD^3}{5.1}$; hence the equation representing full equality of strength between the shaft and the coupling, depending upon the shearing strength of the bolts, is:

$$\frac{SD^3}{5.1R} = \frac{S\pi d^2}{4} n. \qquad (97)$$

The theory of the other types of couplings is obscure, except as regards the proportions of the key, which are the same in all cases. The shell of the clamp coupling, Fig. 52, should be thick enough to give equal torsional strength with the shaft; but the exact function which the bolts perform is difficult to determine. In general the bolts clamp the coupling tightly on the shaft and provide rigidity, but the key does the principal amount of the driving. The bolt sizes, in these couplings, are based on judgment and relation to surrounding parts, rather than on theory.

PRACTICAL MODIFICATION. -All couplings must be made with care and nicely fitted, for their tendency, otherwise, is to spring the shafts out of line. In the case of the flange coupling, the two halves may be keyed in place on the shafts, the latter then swung on centers in the lathe, and the joint faced off. Thus the joint will be true to the axis of the shaft; and, when it is clamped in position by the bolts, no springing out of line can take place.

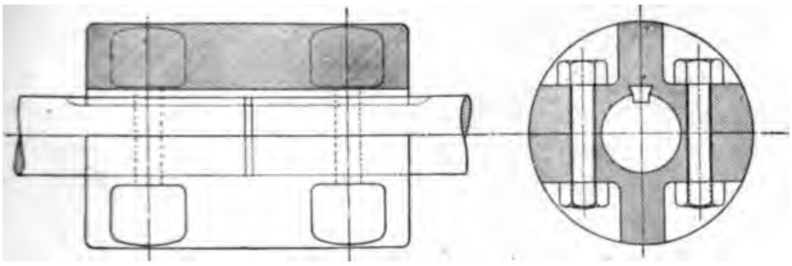


Fig. 52.

A flange F (see Fig. 51) is sometimes made on this form of coupling, in order to guard the bolts. It may be used, also, to take a light belt for driving machinery; but a side load is thereby thrown on the shaft at the joint, which is at the very point where it is desirable to avoid it.

The simplest form of rigid coupling consists of a plain sleeve slipped over from one shaft to the other, when the second is butted up against the first. This is known as a **muff coupling.** When once in place, this is a very excellent coupling, as it is perfectly smooth on the outside, and consists of the fewest possible parts, merely a sleeve and a key. It is, however, expensive to fit, difficult to remove, and requires an extra space of half its length on the shaft over which to be slipped back.

The **clamp coupling** is a good coupling for moderate-sized shafts, where the flange type of Fig. 51 would be unnecessarily expensive. The clamp coupling, Fig. 52, is simply a muff coupling split in halves, and recessed for bolts. It is cheap and is easily applied and removed, even with a crowded shaft. If bored with a piece of paper in the joint, when it is clamped in position it will pinch the shaft tightly and make a rigid connection. It is desirable to have the bolt-heads protected as much as possible, and this may be accomplished by making the outside diameter large enough so that the bolts will not project. Often an additional shell is provided to encase the coupling completely after it is located.

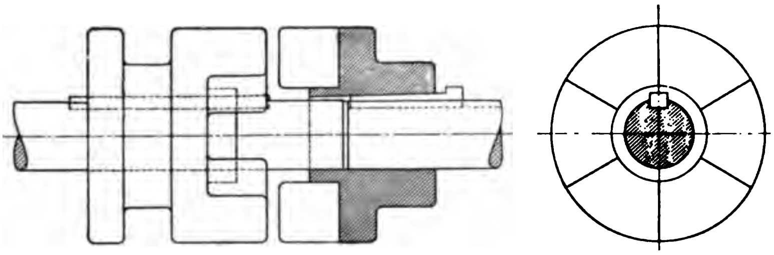


Fig. 53.

There are many other special forms of couplings, some of them adjustable. Most of them depend upon a wedging action exerted by taper cones, screws, or keys. Trade catalogues are to be sought for their description.

The **claw coupling**, Fig. 53, is nothing but a heavy flange coupling with interlocking claws or jaws on the faces of the flanges, to take the place of the driving bolts. This coupling can be thrown in or out as desired, although it usually performs the service of a rigid coupling, as it is not suited to clutching-in during rapid motion, like a friction clutch.

Flexible couplings, which allow slight lack of alignment, are made by introducing between the flanges of a coupling a flexible disc, the one flange being fastened to the inner circle of the disc, the other to the outer circle. This is also accomplished by providing the faces of the flange coupling with pins that drive by pressure together or through leather straps wrapped round the pins. These devices are mostly of a special and often uncertain nature, lacking the positiveness which is one essential feature of a good coupling.

PROBLEMS ON COUPLINGS.

1. A flange coupling of the type of Fig. 51 is used on a shaft 2 inches is diameter. The hub is 3 inches long, and carries a standard key, of proportions indicated below in the table of "Proportions for Gib Keys" (page 166). The bolt circle is 7 inches in diameter, and it is desired to use $\frac{5}{8}$-inch bolts. How many bolts are needed to transmit 60,000 inch-lbs., for a fiber stress in the bolt of 6,000?

2. Using 6 bolts, what diameter of bolt would be required?

3. If four $\frac{3}{4}$-inch bolts were used on a circle of 8 inches diameter, what diameter of shaft would be used in the coupling to give equal strength with the bolts?

BOLTS, STUDS, NUTS, AND SCREWS.

NOTATION—The following notation is used throughout the chapter on Bolts, Studs, Nuts, and Screws:

d = Diameter of bolt (inches).
d_1 = Diameter at root of thread (inches).
H = Height of nut (inches).
I = Initial axial tension (lbs.).
k = Allowable bearing pressure on surface of thread (lbs. per sq. in.).
L = Lead, or distance nut advances along axis in one revolution (inches).
l = Length of wrench handle (inches)
n = Number of threads in nut $= \frac{H}{p}$.
P = Axial load (lbs.).
p = Pitch of thread, or distance between similar points on adjacent threads, measured parallel to axis (inches).
S = Fiber stress (lbs. per sq. in.).
W = Load on bolt (lbs.).

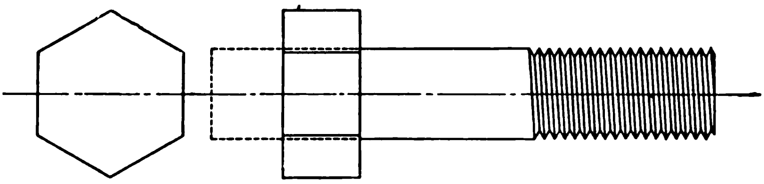


Fig. 54.

ANALYSIS. A **bolt** is simply a cylindrical bar of metal upset at one end to form a head, and having a thread at the other end, Fig. 54. A **stud** is a bolt in which the head is replaced by a thread; or it is a cylindrical bar threaded at both ends, usually having a small plain portion in the middle, Fig. 55. The object of bolts and studs is to clamp machine parts together, and yet permit these same parts to be readily disconnected. The bolt passes through the pieces to be connected, and, when tightened, causes surface compression between the parts, while the reactions on the head and nut produce tension in the bolt. Studs and tap bolts pass through one of the connected parts and are screwed into the other, the stud remaining in position when the parts are disconnected.

As all materials are elastic within certain limits, the action of a bolt in clamping two machine parts together, more especially if there is an elastic packing between them, may be represented diagrammatically by Fig. 56, in which a spring has been introduced to take the compression due to screwing up the nut. Evidently the tension in the bolt is equal to the force necessary to compress the spring. Now, suppose that two weights, each equal to $\frac{1}{2}$ W, are placed symmetrically on either side of the bolt, then the tension in the bolt will be increased by the added weights if the bolt is perfectly rigid. The bolt, however, stretches; hence some of the compression on the spring is relieved and the total tension in the

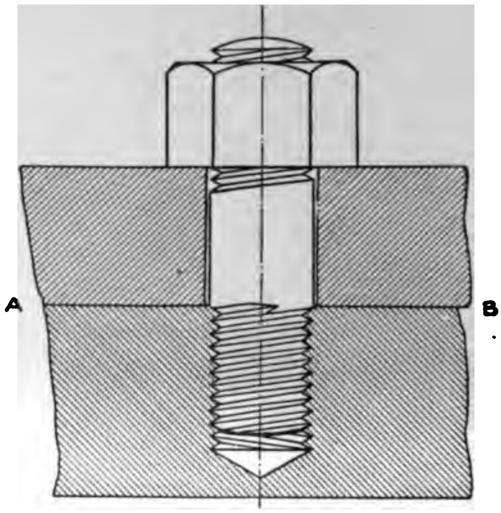


Fig. 55.

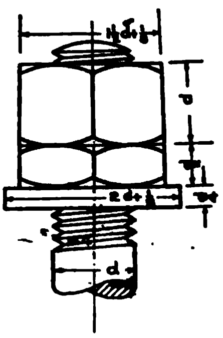


Fig. 55*a*.

bolt is less than W + I, by an amount depending on the relative elasticity of the bolt and spring.

Suppose that the stud in Fig. 55 is one of the studs connecting the cover to the cylinder of a steam engine, and that the studs have a small initial tension; then the pressure of the steam loads each stud, and, if the studs stretch enough to relieve the initial pressure between the two surfaces, then their stress is due to the steam pressure only; or, from Fig. 56, when I = W; the initial pressure due to the elasticity of the joint is entirely relieved by the assumed stretch of the studs. Except to prevent leakage, it is seldom necessary to consider the initial tension, for the stretch of the bolt may be counted on to relieve this force, and the working tension on the bolt is simply the load applied.

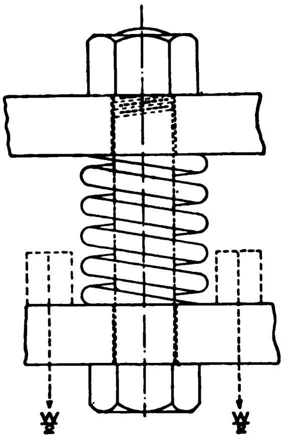


Fig. 56.

For shocks or blows, as in the case of the bolts found on the marine type of connecting-rod end, the stretch of the bolts acts like a spring to reduce the resulting tensions. So important is this feature that the body of the bolt is frequently turned down to the diameter of the bottom of the thread, thus uniformly distributing the stretch through the full length of the bolt, instead of localizing it at the threaded parts.

In tightening up a bolt, the friction at the surface of the thread produces a twisting moment, which increases the stress in the bolts, just as in the case of shafting under combined tension and torsion; but the increase is small in amount, and may readily be taken care of by permitting low values only for the fiber stress.

In a flange coupling, bolts are acted upon by forces perpendicular to the axis, and hence are under pure shearing stress. If the torque on the shaft becomes too great, failure will occur by the bolts shearing off at the joint of the coupling.

A bolt under tension communicates its load to the nut through the locking of the threads together. If the nut is thin, and the number of threads to take the load few, the threads may break or shear off at the root. With a V thread there is produced a component force, perpendicular to the axis of the bolt, which tends to split the nut.

In screws for continuous transmission of motion and power, the thread may be compared to a rough inclined plane, on which a small block, the nut, is being pushed upward by a force parallel to the base of the plane. The angle at the bottom of the plane is the angle of the helix, or an angle whose tangent is the lead divided by the circumference of the screw. The horizontal force corresponds to the tangential force on the screw. The friction at the surface of the thread produces a twisting moment about the axis of the screw, which, combined with the axial load, subjects the screw to combined tension and torsion. Screws with square threads are generally used for this service, the sides of the thread exerting no bursting pressure on the nut. The proportions of screw thread for transmission of power depend more on the bearing pressure than on strength. If the bearing surface be too small and lubrication poor, the screw will cut and wear rapidly.

THEORY. A direct tensile stress is induced in a bolt when it carries a load exerted along its axis. This load must be taken by the section of the bolt at the bottom of the thread. If the area at the root of the thread is $\frac{\pi d_1^2}{4}$, and if S is the allowable stress per square inch, then the internal resistance of the bolt is $\frac{S\pi d_1^2}{4}$. Equating the external load to the internal strength we have:

$$W = \frac{S\pi d_1^2}{4}. \qquad (98)$$

For bolts which are used to clamp two machine parts together so that they will not separate under the action of an applied load, the initial tension of the bolt must be at least equal to the applied load. If the applied load is W, then the parts are just about to separate when I = W. Therefore the above relation for strength is applicable. As the initial tension to prevent separation should be a little greater than W, a value of S should be chosen so that there will be a margin of safety. For ordinary wrought iron and steel, S may be taken at 6,000 to 8,000.

If, however, the joints must be such that there is no leakage between the surfaces, as in the case of a steam cylinder head, and supposing that elastic packings are placed in the joints, then a much larger margin should be made, for the maximum load which may come on the bolt is I + W, where W is the proportional share of the internal pressure carried by the bolt. In such cases $S = 3{,}000$ to $5{,}000$, using the lower value for bolts of less than $\frac{7}{8}$-inch diameter.

The table given on page 154 will be found very useful in proportioning bolts with U. S. standard thread for any desired fiber stress.

To find the initial tension due to screwing up the nut, we may assume the length of the handle of an ordinary wrench, measured from the center of the bolt, as about 16 times the diameter of the bolt. For one turn of the wrench a force F at the handle would pass over a distance $2\pi l$, and the work done is equal to the product of the force and space, or $F \times 2\pi l$. At the same time the axial load P would be moved a distance p along the axis. Assuming that there is no friction, the equation for the equality of the work at the handle and at the screw is:

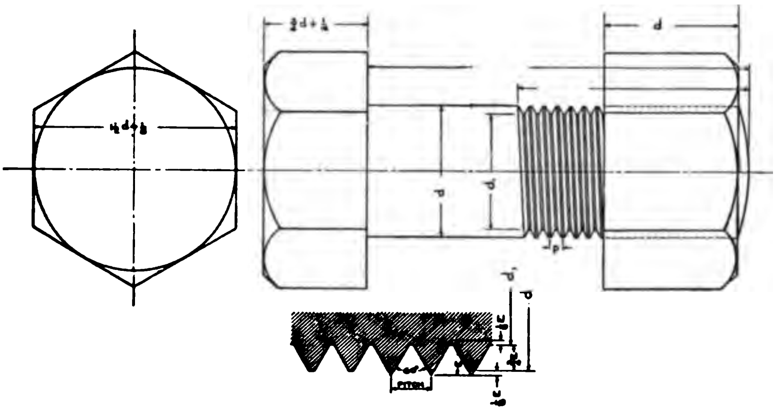


Fig. 56*a*.

$$F2\pi l = Pp. \qquad (99)$$

Friction, however, is always present; hence the ratio of the useful work (Pp) to the work applied ($F2\pi l$) is not unity as above re-

TABLE FOR STRENGTH OF BOLTS.—U. S. Standard Thread.

Bolt.		Diameters.		Areas.		Approximate Tensile Strength. at Bottom of Thread. (In Hundreds of Pounds.)					Approximate Shearing Strength. Full Bolt Diameter. (In Hundreds of Pounds.)			
Diameter. Inches.	Threads per inch.	Bottom of Thread.	Tap Drill.	Bolt Body.	Bottom of Thread.	At 4,000 lbs. per sq. in.	At 5,000 lbs. per sq. in.	At 6,000 lbs. per sq. in.	At 7,000 lbs. per sq. in.	At 10,000 lbs. per sq. in.	At 4,000 lbs. per sq. in.	At 5,000 lbs. per sq. in.	At 6,000 lbs. per sq. in.	At 7,000 lbs. per sq. in.
1/4	20	.18	13/64	.05	.03	1.08	1.35	1.60	1.88	2.69	1.96	2.45	2.95	3.43
5/16	18	.24	1/4	.08	.04	1.82	2.27	2.72	3.18	4.54	3.04	3.83	4.60	5.37
3/8	16	.29	5/16	.11	.07	2.71	3.39	4.07	4.75	6.78	4.40	5.52	6.62	7.73
7/16	14	.34	23/64	.15	.09	3.73	4.67	5.60	6.53	9.33	6.00	7.51	9.02	11.00
1/2	13	.40	13/32	.20	.13	5.00	6.25	7.50	8.75	12.00	7.84	9.81	12.00	14
9/16	12	.45	15/32	.25	.16	6.48	8.10	9.62	11.00	16	9.92	12.00	15	17
5/8	11	.51	17/32	.31	.20	8.01	10.00	12.00	14	20	12.00	15	18	21
3/4	10	.62	5/8	.44	.30	12.00	15	18	21	30	18	22	26	31
7/8	9	.73	3/4	.60	.42	17	24	25	29	42	24	30	36	42
1	8	.84	27/32	.78	.55	22	27	33	38	55	31	39	47	55
1 1/8	7	.94	31/32	.99	.69	28	34	41	48	69	40	50	60	70
1 1/4	7	1.06	1 3/32	1.23	.89	31	39	47	55	78	49	61	74	86
1 3/8	6	1.16	1 3/16	1.48	1.05	42	53	64	72	106	59	74	89	104
1 1/2	6	1.28	1 9/32	1.77	1.29	51	64	77	90	128	71	88	106	124
1 5/8	5 1/2	1.39	1 13/32	2.07	1.51	61	78	92	109	153	83	104	124	145
1 3/4	5	1.49	1 1/2	2.40	1.74	70	88	106	123	176	96	120	144	168
1 7/8	5	1.61	1 5/8	2.76	2.05	81	101	122	142	203	110	138	166	193
2	4 1/2	1.71	1 3/4	3.14	2.30	92	115	138	161	230	126	157	186	220
2 1/4	4 1/2	1.96	1 31/32	3.98	3.02	125	156	187	218	312	159	199	238	278
2 1/2	4	2.17	2 3/16	4.91	3.72	148	185	222	259	370	196	245	294	344
2 3/4	4	2.42	2 7/16	5.94	4.62	184	230	276	322	460	237	297	356	416
3	3 1/2	2.63	2 5/8	7.07	5.43	218	272	326	381	544	283	353	424	495
3 1/4	3 1/2	2.88	2 29/32	8.29	6.51	264	330	396	462	660	332	415	498	581
3 1/2	3 1/4	3.10	3 1/32	9.62	7.55	302	376	452	528	754	385	481	577	673
3 3/4	3	3.32	3 11/32	11.04	8.64	344	430	516	602	860	442	552	663	773
4	3	3.57	3 19/32	12.57	9.99	396	495	594	693	990	503	628	754	880
4 1/4	2 7/8	3.80	3 13/16	14.19	11.33	452	565	678	791	1,130	567	709	851	993
4 1/2	2 3/4	4.03	4 1/32	15.90	12.71	507	634	760	888	1,268	636	795	951	1,113
4 3/4	2 5/8	4.25	4 9/32	17.72	14.22	567	709	851	1.993	1,420	709	886	1,063	1,240
5	2 1/2	4.48	4 1/2	19.63	15.76	630	788	946	1.103	1,676	785	982	1,178	1,374
5 1/2	2 3/8	4.95	4 31/32	23.76	19.27	770	962	1.154	1.347	1,924	950	1.188	1.425	1.663
6	2 1/4	5.42	5 7/16	28.27	23.00	923	1.150	1.384	1.617	2,307	1,128	1.414	1.696	1,979

s assume. From numerous experiments on the friction of s and nuts, it has been found that the efficiency may be as as 10 per cent. Introducing the efficiency in above equation, ay be written:

$$\frac{Pp}{F2\pi l} = \frac{1}{10}. \qquad (100)$$

Assuming that 50 pounds is exerted by a workman in tightening up the nut on a 1-inch bolt, the equation above shows that $P = 4,021$ pounds; or the initial tension is somewhat less than the tabular safe load shown for a 1-inch bolt, with S assumed at 10,000 pounds per sq. inch.

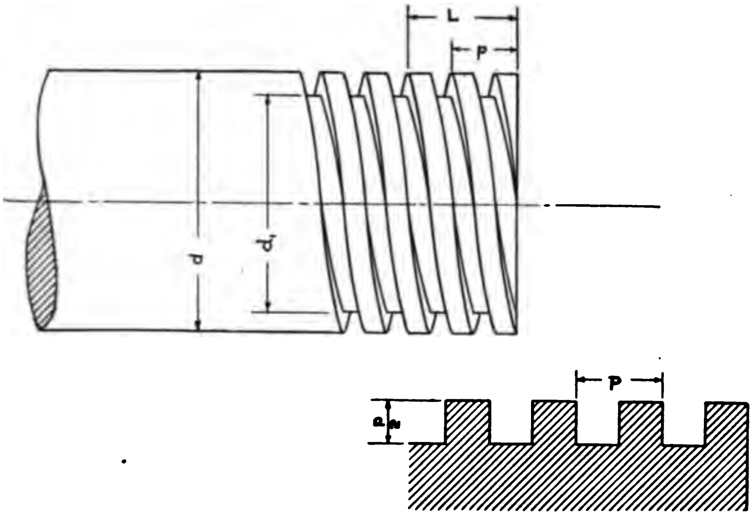


Fig. 58.

For shearing stresses the bolt should be fitted so that the body of the bolt, not the threads, resists the force tending to shear off the bolt perpendicular to its axis. The internal strength of the bolt to resist shear is the allowable stress S times the area of the bolt in shear, or $\frac{S\pi d^2}{4}$. If W represents the external force tending to shear the bolt the equality of the external force to the internal strength is:

$$W = \frac{S\pi d^2}{4}. \qquad (101)$$

Reference to the table on page 154 for the shearing strength of bolts, may be made to save the labor of calculations.

Let Fig. 58 represent a square thread screw for the transmission of motion. The surface on which the axial pressure bears, if n is the number of threads in a nut, is $\frac{\pi}{4}(d^2 - d_1^2)\ n$. Suppose that a pressure of k pounds per square inch is allowed on the surface of the thread. Then the greatest permissible axial load P must not exceed the allowable pressure; or, equating,

$$P = k\ \frac{\pi}{4}(d^2 - d_1^2)\ n \qquad (102)$$

The value of k varies with the service required. If the motion be slow and the lubrication very good, k may be as high as 900. For rapid motion and doubtful lubrication, k may not be over 200. Between these extremes the designer must use his judgment, remembering that the higher the speed the lower is the allowable bearing pressure.

PRACTICAL MODIFICATION. It will be noted in the formulæ for bolt strengths that different values for S are assumed. This is necessary on account of the uncertain initial stresses which are produced is setting up the nuts. For cases of mere fastening, the safe tension is high, as just before the joint opens the tension is about equal to the load and yet the fastening is secure. On the other hand, bolts or studs fastening joints subjected to internal fluid pressure must be stressed initially to a greater amount than the working pressure which is to come on the bolt. As this initial stress is a matter of judgment on the part of the workman, the designer, in order to be on the safe side, should specify not less than ⅝-inch or ¾-inch bolts for ordinary work, so that the bolts may not be broken off by a careless workman accidentally putting a greater force than necessary on the wrench handle. In making a steam-tight joint, the spacing of the bolts will generally determine their number; hence we often find an excess of bolt strength in joints of this character.

Through bolts are preferred to studs, and studs to tap bolts or cap screws. If possible, the design should be such that through bolts may be used. They are cheapest, are always in standard stock, and well resist rough usage in connecting and disconnecting. The threads in cast iron are weak and have a tendency to crumble; and if a through bolt cannot be used in such a case, a stud, which can be placed in position once for all, should be employed—not a tap bolt, which injures the thread in the casting every time it is removed.

The plain portion of a stud should be screwed up tight against the shoulder, and the tapped hole should be deep enough to prevent bottoming. To avoid breaking off the stud at the shoulder, a neck, or groove, may be made at the lower end of the thread entering the nut.

To withstand shearing forces the bolts must be fitted so that no lost motion may occur, otherwise pure shearing will not be secured.

Nuts are generally made hexagonal, but for rough work are often made square. The hexagonal nut allows the wrench to turn through a smaller angle in tightening up, and is preferred to the square nut. Experiments and calculations show that the height of the nut with standard threads may be about ½ the diameter of the bolt and still have the shearing strength of the thread equal to the tensile strength of the bolt at the root of the thread. Practically, however, it is difficult to apply such a thin wrench as this proportion would call for on ordinary bolts. More commonly the height of the nut is made equal to the diameter of the bolt so that the length of thread will guide the nut on the bolt, give a low bearing pressure on the threads, and enable a suitable wrench to be easily applied. The standard proportions for bolts and nuts may be found in any handbook. Not all manufacturers conform to the United States standard; nor do manufacturers in all cases conform to one another in practice.

If the bolt is subject to vibration, the nuts have a tendency to loosen. A common method of preventing this is to use double nuts, or **lock nuts**, as they are called (see Fig. 55 A). The under nut is screwed tightly against the surface, and held by a wrench while the second nut is screwed down tightly against the first. The effect is to cause the threads of the upper nut to bear against the under sides of the threads of the bolt. The load on the bolt is sustained therefore by the upper nut, which should be the thicker of the two; but for convenience in applying wrenches the position of the nuts is often reversed.

The form of thread adapted to transmitting power is the square thread, which, although giving less bursting pressure on the nut, is not as strong as the V thread for a given length, since the total section of thread at the bottom is only $\frac{1}{2}$ as great. If the pressure is to be transmitted in but one direction, the two types may be combined advantageously to form the buttress thread of the proportions shown in Fig. 59. Often, as in the carriage of a lathe, to allow the split nut to be opened and closed over the lead screw, the sides of the thread are placed at a small angle, say 15°, to each other, as illustrated in Fig. 60.

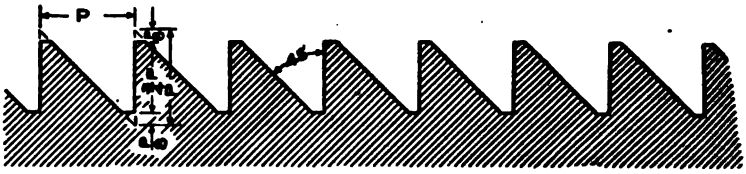


Fig. 59.

The practical commercial forms in which we find screwed fastenings are included in five classes, as follows:

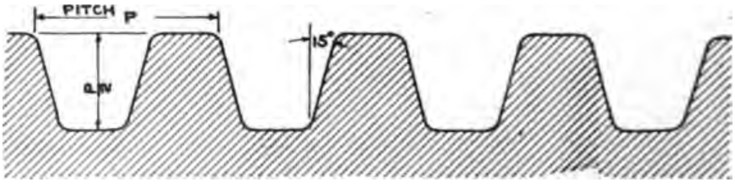


Fig. 60.

1. **Through bolts** (Fig. 61), usually rough stock, with square upset heads, and square or hexagonal nuts.

2. **Tap bolts** (Fig. 62), also called **cap screws**. These usually have hexagonal heads, and are found both in the rough form, and finished from the rolled hexagonal bar in the screw machine.

3. **Studs** (Fig. 63), rough or finished stock, threaded in the screw machine.

4. **Set screws** (Fig. 64), usually with square heads, and case-hardened points. Many varieties of set screws are made, the

principal distinguishing feature of each being in the shape of the point. Thus, in addition to the plain beveled point, we find the "cupped," rounded, conical, and "teat" points.

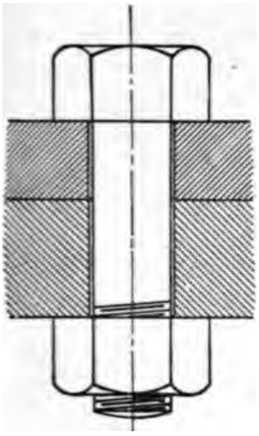


Fig. 61.

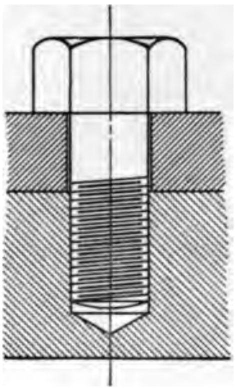


Fig. 62.

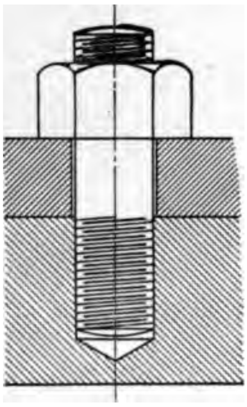


Fig. 63.

5. **Machine screws** (Fig. 64*a*), usually round, "button," r countersunk head. Common proportions are indicated relative o diameter of body of screw.

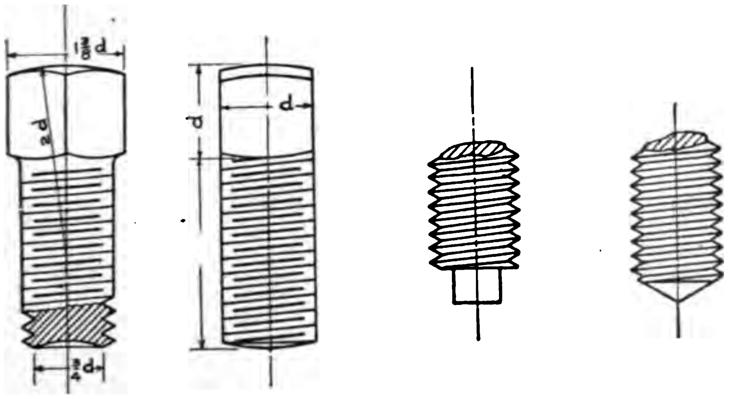


Fig. 64.

PROBLEMS ON BOLTS, STUDS, NUTS, AND SCREWS.

1. Calculate the diameter of a bolt to sustain a load of 5,000 lbs.

2. The shearing force to be resisted by each of the bolts of a flange coupling is 1,200 lbs. What commercial size of bolt is required?

3. With a wrench 16 times the diameter of the bolt, and an efficiency of 10 per cent, what axial load can a man exert on a standard $\frac{3}{4}$-inch bolt, if he pulls 40 lbs. at the end of the wrench handle?

4. A single, square-threaded screw of diameter 2 inches, lead $\frac{1}{4}$ inch, depth of thread $\frac{1}{8}$ inch, length of nut 3 inches, is to be allowed a bearing pressure of 300 lbs. per square inch. What axial load can be carried?

5. Calculate the shearing stress at the root of the thread in problem 4.

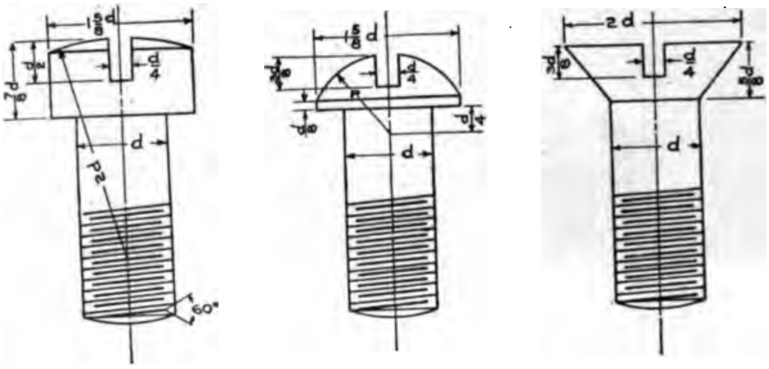


Fig. 64*a*.

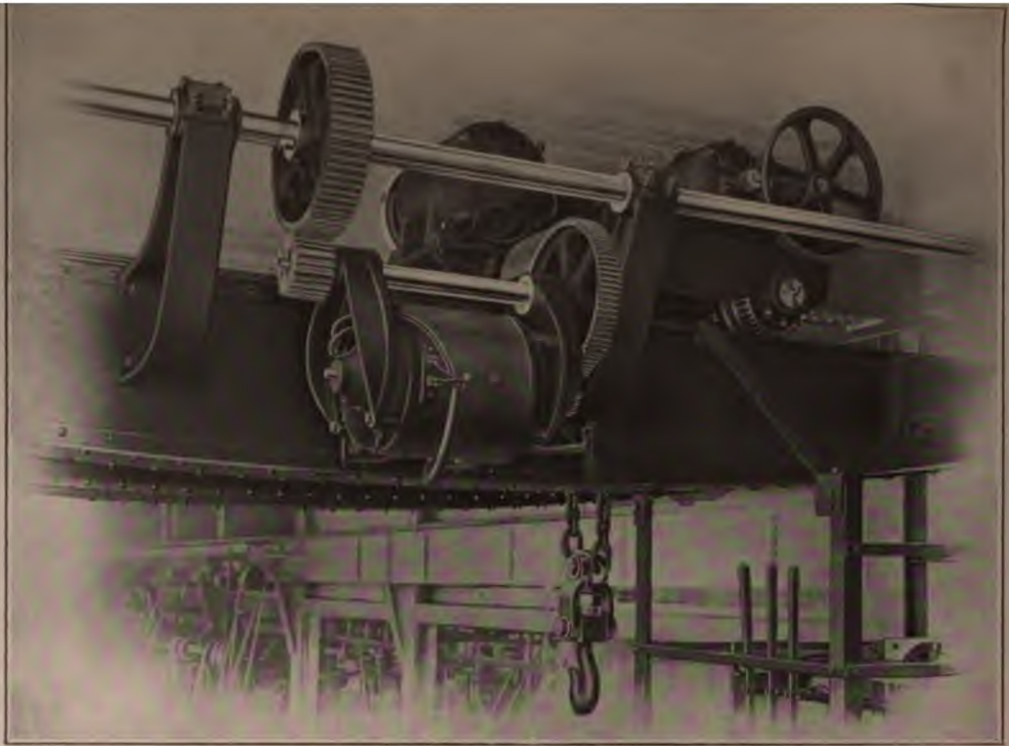
KEYS, PINS, AND COTTERS.

NOTATION—The following notation is used throughout the chapter on Keys, Pins, and Cotters:

D = Average diameter of rod (inches).
D_1 = Outside diameter of socket (inches).
d = Diameter of shaft (inches).
L = Length of key (inches).
P = Driving force (lbs.).
P_1 = Axial load on rod (lbs.).
R = Radius at which P acts (inches).
S_c = Safe crushing fiber stress (lbs. per sq. in.).
S_s = Safe shearing fiber stress (lbs. per sq. in.).
S_t = Safe tensile fiber stress (lbs. per sq. in.).
T = Thickness of key (inches).
W = Width of key (inches).
w = Average width of cotter (inches).
w_1 = End of slot to end of rod (inches).
w_2 = End of slot to end of socket (inches).

KEYS AND PINS.

ANALYSIS. Keys and pins are used to prevent relative



ELECTRIC CRANE DRIVEN BY WESTINGHOUSE TYPE L MOTORS

rotary motion between machine parts intended to act together as one piece. If we drill completely through a hub and across the shaft, and insert a tightly fitted pin, any rotary motion of the one will be transmitted to the other, provided the pin does not fail by shearing off at the joint between the shaft and the hub. The shearing area is the sum of the cross-sections of the pin at the joint.

We may drill a hole in the joint, the axis of the hole being parallel to the axis of the shaft, and drive in a pin, in which case we introduce a shearing area as before, but the area is now equal to the diameter of the pin multiplied by its length, and the pin is stressed sidewise, instead of across. It is evident in the sidewise case that we may increase the shearing area to anything we please, without changing the diameter of the pin, merely by increasing the length of the pin.

As there are some manufacturing reasons why a round pin placed lengthwise in the joint is not always applicable, we may make the pin a rectangular one, in which case it is called a **key.**

When pins are driven across the shaft as in the first instance, they are usually made taper. This is because it is easier to ream a taper hole to size than a straight hole, and a taper pin will drive more easily than a straight pin, it not being necessary to match the hole in hub and shaft so exactly in order that the pin may enter. The taper pin will draw the holes into line as it is driven, and can be backed out readily in removal.

Keys of the rectangular form are either straight or tapered, but for different reasons from those just stated for pins. Straight keys have working bearing only at the sides, driving purely by shear, crushing being exerted by the side of the key in both shaft and hub, over the area against the key. The key itself does not prevent end motion along the shaft; and if end motion is not desired, auxiliary means of some sort must be resorted to, as, for example, set screws through the hub jamming hard against the top of the key.

If end motion along the shaft is desired, the key is called a **spline,** and, while not jammed against the shaft, is yet prevented from changing its relation to the hub by some means such as illustrated in Fig. 65.

Taper keys not only drive through sidewise shearing strength, but prevent endwise motion by the wedging action exerted between the shaft and hub. These keys drive more like a strut from corner to corner; but this action is incidental rather than intentional, and the proportions of a taper key should be such that it will give its full resisting area in shearing and crushing, the same as a straight key.

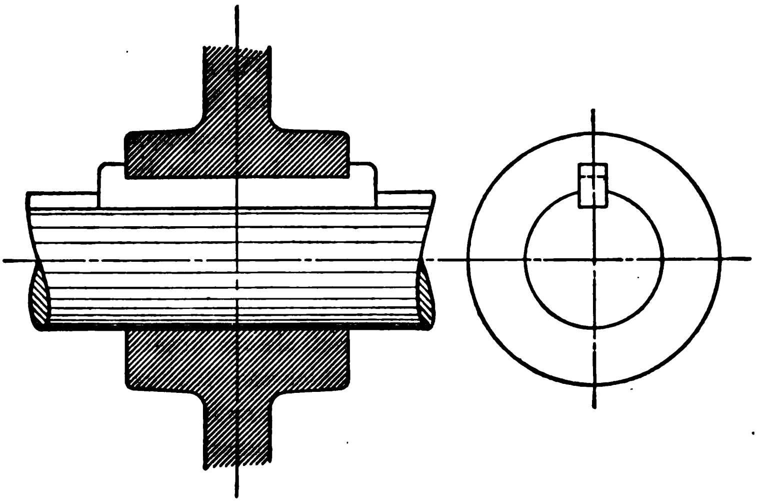


Fig. 65.

THEORY. Suppose that the pin illustrated in Fig. 66 passes through hub and shaft, and the driving force P acts at the radius R; then the force which is exerted at the surface of the shaft to shear off the pin at the points A and B is $\frac{2\,PR}{d}$. If D_1 is the average diameter of the pin, its shearing strength is $\frac{2\pi D_1^2 S_s}{4}$. Equating the external force to the internal strength, we have:

$$\frac{2PR}{d} = \frac{2\pi D_1^2\, S_s}{4};$$

or,

$$D_1 = \sqrt{\frac{4PR}{\pi d S_s}}. \qquad (103)$$

In Fig. 67 a rectangular key is sunk half way in hub and shaft according to usual practice. Here the force at the surface of the shaft, calculated the same as before, not only tends to shear off the key along the line AB, but tends to crush both the portion in the shaft and in the hub. The shearing strength along the line AB is LWS_s. Equating external force to internal strength, we have:

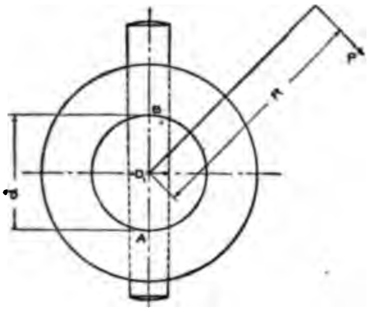


Fig. 66.

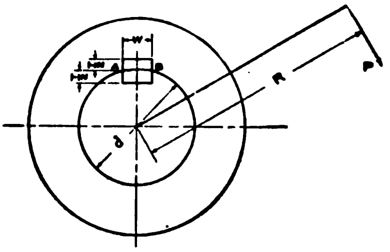


Fig. 67.

$$\frac{2PR}{d} = LWS_s;$$

or,
$$W = \frac{2PR}{dLS_s}. \qquad (104)$$

The crushing strength is, of course, that due to the weaker metal, whether in shaft or hub. Let S_c be this least safe crushing fiber stress. The crushing strength then is $\frac{LT}{2} S_c$, and, equating external force to internal strength, we have:

$$\frac{2PR}{d} = \frac{LT}{2} S_c;$$

or,
$$T = \frac{4PR}{dLS_c}. \qquad (105)$$

The proportions of the key must be such that the equations as above, both for shearing and for crushing, shall be satisfied.

PRACTICAL MODIFICATION. Pins across the shaft can be used to drive light work only, for the shearing area cannot be very large. A large pin cuts away too much area of the shaft, decreasing the latter's strength, Pins are useful in preventing end motion, but in this case are expected to take no shear, and may be of small diameter. The common split pin is especially adapted to t service, and is a standard commercial article.

Taper pins are usually listed according to the Morse standa taper, proportions of which may be found in any handbook. is desirable to use *standard* taper pins in machine construction, the reamers are a commercial article of accepted value, and readil obtainable in the machine-tool market.

With properly fitted keys, the shearing strength is usually the controlling element. For shafts of ordinary size, the standard proportions as given in tables like that below are safe enough without calculation, up to the limit of torsional strength of the shaft. For special cases of short hubs or heavy loads, a calculation is needed to check the size, and perhaps modify it.

Splines, also known as "feather keys," require thickness greater than regular keys, on account of the sliding at the sides. A table suggesting proportions for splines is given on page 166.

Though the spline may be either in the shaft or hub, it is the more usual thing to find the spline dovetailed (Fig. 67*a*), "gibbed," or otherwise fastened in the hub; and a long spline way made in the shaft, in which it slides.

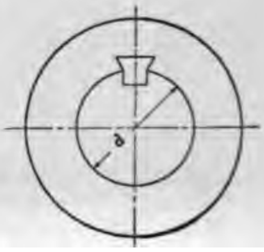


Fig. 67*a*.

The straight key, accurately fitted, is the most desirable fastening device for accurate machines, such as machine tools, on account of the fact that there is absolutely no radial force exerted to throw the parts out of true. It, however, requires a tight fit of hub to shaft, as the key cannot be relied upon to take up any looseness.

The taper key (Fig. 68), by its wedging action, will take up some looseness, but in so doing throws the parts out slightly. Or, even if the bored fit be good, if the taper key be not driven home with care, it will spring the hub, and make the parts run untrue. The great advantage, however, that the taper key has of holding the hub from endwise motion, renders it a very useful and practical article. It is usually provided with a head, or "gib," which permits a draw hook to be used to wedge between the face of the hub and the key to facilitate starting the key from its seat.

Two keys at 90° from each other may be used in cases where one key will not suffice. The fine workmanship involved in spacing these keys so that they will drive equally makes this plan inadvisable except in case of positive and unavoidable necessity.

The "Woodruff" key (Fig. 69) is a useful patented article for certain locations. This key is a half-disc, sunk in the shaft and the hub is slipped over it. A simple rotary cutter is dropped into the shaft to produce the key seat; and on account of the depth in the shaft, the tendency to rock sidewise is eliminated, and the drive is purely by shear.

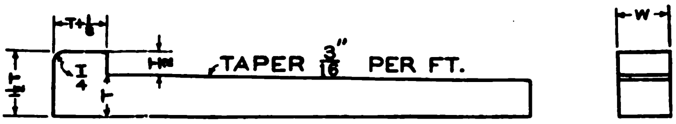


Fig. 68.

Keys may be milled out of solid stock, or drop-forged to within a small fraction of finished size. The drop-forged key is an excellent modern production and requires but a minimum amount of fitting. Any key, no matter how produced, requires some hand fitting and draw filing to bring it properly to its seat and give it full bearing.

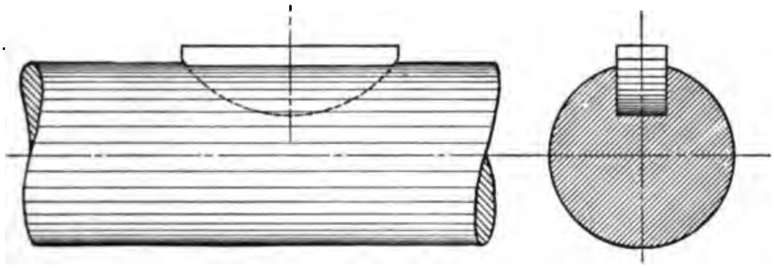


Fig. 69.

It is good mechanical policy to avoid keyed fastenings whenever possible. This does not mean that keys may never be used, but that a key is not an ideal way to produce an absolutely positive drive, partly because it is an expensive device, and partly because the tendency of any key is to work itself loose, even if carefully fitted.

The following tables are suggested as a guide to proportions of gib keys and feather keys, and will be found useful in the. absence of any manufacturer's standard list:

Fig. 70. **PROPORTIONS FOR GIB KEYS.**

Diameter of shaft (*d*), inches.	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{5}{8}$	2	$2\frac{1}{2}$	$3\frac{1}{4}$	4	5	$6\frac{1}{2}$
Width (W), inches.	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{11}{16}$	$\frac{7}{8}$	$1\frac{1}{16}$	$1\frac{5}{16}$	$1\frac{5}{8}$
Thickness (T), inches.	$\frac{1}{4}$	$\frac{9}{32}$	$\frac{5}{16}$	$\frac{13}{32}$	$\frac{7}{16}$	$\frac{17}{32}$	$\frac{21}{32}$	$\frac{13}{16}$	1	$1\frac{1}{4}$

Fig. 71. **PROPORTIONS FOR FEATHER KEYS.**

Diameter of Shaft (*d*), inches,	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	2	$2\frac{1}{4}$	$2\frac{1}{2}$	3	$3\frac{1}{2}$	4	$4\frac{1}{2}$
Width (W), inches.	$\frac{3}{16}$	$\frac{7}{32}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{9}{16}$	$\frac{5}{8}$
Thickness (T), inches.	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{7}{8}$

COTTERS.

ANALYSIS. Cotters are used to fasten hubs to rods rather than shafts, the distinction between a rod and a shaft being that a rod takes its load in the direction of its length, and does not drive by rotation. A cotter, therefore, is nothing but a cross-pin of modified form, to take shearing and crushing stress in the direction of the axis of the rod, instead of perpendicular to it.

Referring to Fig. 72, one will see that the cotter is made long and thin--long, in order to get sufficient shearing area to resist shearing along lines A and B; thin, in order to cut as little cross-sectional area out of the body of the shaft as possible. The cotter itself tends to shear along the lines A and B, and crush along the surfaces K, G, and J. The socket tends to crush along the surfaces K and G. The rod end D tends to be sheared out along the lines C H and Q E, and also to be crushed along the surface J. The socket tends to be sheared along the lines V U and X Y.

The cotter is made taper on one side, thus enabling it to draw up the flange of the rod tightly against the head of the socket. This taper must not be great enough to permit easy "backing out" and loosening of the cotter under load or vibration in the rod. In responsible situations this cannot be safely guarded against except through some auxiliary locking device, such as lock nuts on the end of the cotter (Fig. 73).

THEORY. Referring to Fig. 72, assume an axial load of P_1, as shown. The successive equations of external force to internal strength are enumerated below, for the different actions that take place:

For shearing along lines A and B, w being the average width of cotter, and S_s safe shearing stress of cotter,

$$P_1 = 2TwS_s. \qquad (106)$$

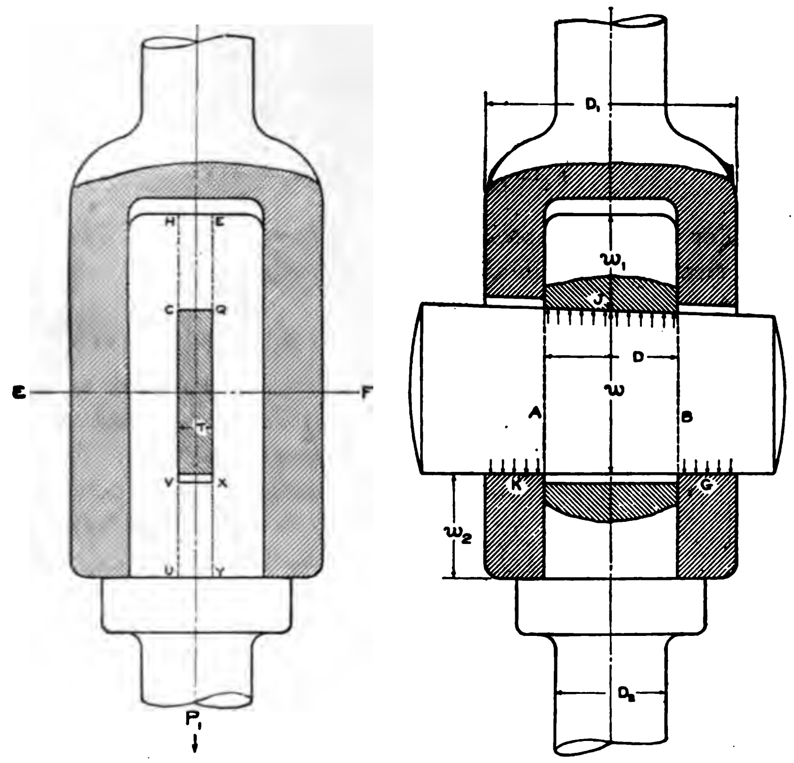


Fig. 72.

For crushing along surfaces K and G, S_c being least safe crushing stress, whether of cotter or socket,

$$P_1 = T(D_1 - D)S_c. \qquad (107)$$

For crushing along surface J, S_c being least safe crushing stress, whether of cotter or socket,

$$P_1 = DTS_c. \qquad (108)$$

For aring along surfaces CH and QE, S_s being safe she ing stress o rod end, and w_1 end of slot to end of rod,

$$P_1 = 2w_1DS_s. \qquad (109)$$

For tension in rod end at section across slot, S_t being safe tensile stress in rod end,

$$P_1 = (\frac{\pi D^2}{4} - TD)S_t. \qquad (110)$$

For tension in socket at section across slot, S_t being safe tensile stress in socket,

$$P_1 = [\frac{\pi D_1^2}{4} - \frac{\pi D^2}{4} - T(D_1 - D)]S_t. \qquad (111)$$

For shearing in socket along the lines VU and XY, S_s being safe shearing stress in the socket, and w_2 end of slot to end of socket,

$$P_1 = 2w_2(D_1 - D)S_s. \qquad (112)$$

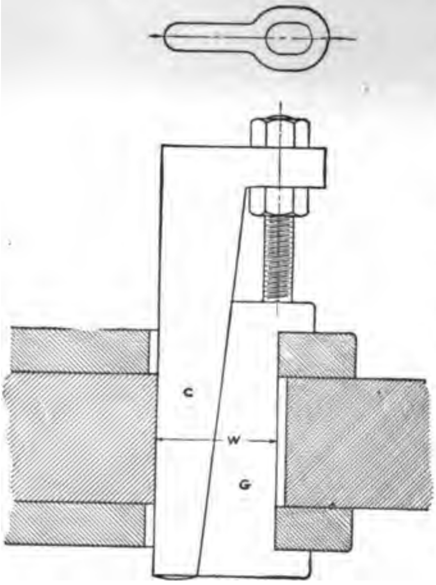


Fig. 73.

The proportions of cotter and socket may be fixed to some extent by practical or assumed conditions. The dimensions may then be tested by the above equations, that the safe working stresses may not be exceeded, the dimensions being then modified accordingly.

The steel of which both cotter and rod would ordinarily be made has range of working fiber stress as follows:

Tension, 8,000 to 12,000 (lbs. per sq. in.)
Compression, 10,000 to 16,000 (lbs. per sq. in.)
Shear, 6,000 to 10,000 (lbs. per sq. in.)

The socket, if made of cast iron, will be weak as regards tension, tendency to shear out at the end, and tendency to split. The uncertainty of cast iron to resist these is so great that the hub or socket must be very clumsy in order to have enough surplus strength. This is always a noticeable feature of the cotter type of fastening, and cannot well be avoided.

PRACTICAL MODIFICATION. The driving faces of the cotter are often made semicircular. This not only gives more shearing area at the sides of the slots, but makes the production of the slots easier in the shop. It also avoids the general objection to sharp corners—namely, a tendency to start cracks.

A practicable taper for cotters is ½ inch per foot. This will under ordinary circumstances prevent the cotter from backing out under the action of the load. When set screws against the side of the cotter, or lock nuts are used, as in Fig. 73, the taper may be greater than this, perhaps as much as 1½ inches per foot.

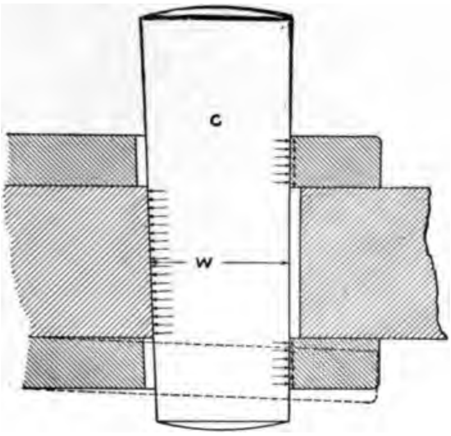


Fig. 74.

In the common use of the cotter for holding the strap at the ends of connecting rods, the strap acts like a modified form of socket. This is shown in Figs. 73 and 74. Here, in addition to holding the strap and rod together lengthwise, it may be necessary to prevent their spreading, and for this purpose an auxiliary piece G with gib ends is used. The tendency without this extra piece is shown by the dotted lines in Fig. 74.

The general mechanical fault with cottered joints is that the action of the load, especially when it constantly reverses, as in pump piston rods, always tends to work the cotter loose. Vibration also tends to produce the same effect. Once this looseness is started in the joint, the cotter loses its pure crushing and shearing action, and begins to partake of the nature of a hammer, and pounds itself and its bearing surfaces out of their true shape. Instead of a collar on the rod, we often find a taper fit of the rod in the socket; and any looseness in this case is still worse, for the rod then has end play in the socket, and by its "shucking" back and forth tends to split open the socket.

The only answer to these objections is to provide a positive locking device, and take up any looseness the instant it appears.

PROBLEMS ON KEYS, PINS, AND COTTERS.

1. Calculate the safe load in shear which can be carried on a key $\frac{1}{2}$ inch wide, $\frac{3}{8}$ inch thick, and 5 inches long. Assume $S_s = 6,000$.

2. Assuming the above key to be $\frac{3}{16}$ inch in hub and $\frac{3}{16}$ inch in shaft, test its proportions for crushing, at $S_c = 16,000$.

3. A gear 60 inches in diameter has a load of 3,000 lbs. at the pitch line. The shaft is 4 inches in diameter, in a hub, 5 inches long; and the key is a standard gib key as given in the table. Test its proportions for shearing.

4. A piston rod 2 inches in diameter carries a cotter $\frac{3}{8}$ inch thick, and has an axial load of 20,000 lbs. Calculate the average width of the cotter. $S_s = 9,000$.

5. Calculate fiber stress in rod in preceding problem at section through slot.

6. How far from the end of rod must the end of slot be?

7. Calculate the crushing fiber stresses on cotter, rod, and socket.

8. How far from the end of socket must the end of slot be, assuming the socket to be of steel ?

BEARINGS, BRACKETS, AND STANDS.

NOTATION—The following notation is used throughout the chapters on Bearings Brackets, and Stands.

A = Area (square inches).
a = Distance between bolt centers (inches).
b = Width of bracket base (inches).
c = Distance of neutral axis from outer fiber (inches).
D = Diameter of shaft (inches).
d = Diameter of bolt body (inches).
d_1 = Diameter at root of thread (inches).
H = Horse-power.
h = Thickness of cap at center (inches).
I = Moment of inertia.
L = Length of bearing (inches).
μ = Coefficient of friction (per cent).

N = Number of revolutions per minute.
n = Number of bolts in cap.
n_1 = Number of bolts in bracket base.
P = Total pressure on bearing (lbs.).
p = Pressure per square inch of projected area (lbs).
S = Safe tensile fiber stress (lbs.).
S_s = " shearing " (lbs.).
T = Total load on bolts at top of bracket (lbs.).
t = Thickness of bracket base (inches).
x = Distance from line of action of load to any section of bracket (inches).

ANALYSIS. Machine surfaces taking weight and pressure of other parts in motion upon them are, in general, known as **bearings.** If the motion is rectilinear, the bearing is termed a **slide, guide,** or **way,** such as the cross slide of a lathe, the crosshead guide of a steam engine, or the ways of a lathe bed.

If the motion is a rotary one, like that of the spindle of a lathe, the simple word "bearing" is generally used.

In any bearing, sliding or rotary, there must be strength to carry the load, stiffness to distribute the pressure evenly over the full bearing surface, low intensity of such pressure to prevent the lubricant from being squeezed out and to minimize the wear, and sufficient radiating surface to carry away the heat generated by friction of the surfaces as fast as it is generated. Sliding bearings are of such varied nature, and exist under conditions so peculiar to each case, that a general analysis is practically impossible beyond that given in the sentence above.

Rotary bearings can be more definitely studied, as there are but two variable dimensions, diameter and length, and it is the proper relation between these two that determines a good bearing. The size of the shaft, as noted under "Shafts," is calculated by taking the bending moment at the center of the bearing, combining it with the twisting moment, and solving for the diameter consistent with the assumed fiber stress. But this size must then be tried for deflection due to the bending load, in order that the requirement for stiffness may be fulfilled. When this is accomplished, the friction at the bearing surface may still generate so much heat that the exposed surface of the bearing will not radiate it as fast as generated, in which case the bearing gets hotter and hotter, until it finally burns out the lubricant and melts the lining of the bearing, and ruin results.

The heat condition is usually the critical one, as it is very easy to make a short bearing which is strong enough and amply stiff for the load it carries, but which nevertheless is a failure as a bearing, because it has so small a radiating surface that it cannot run cool.

The side load which causes the friction and the consequent development of heat, is due to the pull of the belt in the case of pulleys, the load on the teeth of gears, the pull on cranks and levers, the weight of parts, etc. If we could exert pure torsion on shafts without any side pressure, and counteract all the weight that comes on the shaft, we should not have any trouble with the development of heat in bearings; in fact, there would theoretically be no need of bearings, as the shafts would naturally spin about their axes, and would not need support.

It can be shown, theoretically, that the radiating surface of a bearing increases relatively to the heat generated by a given side load, *only when the length of the bearing is increased.* In other words, increasing the diameter and not the length, theoretically increases the heat generated per unit of time just as much as it increases the radiating surface; hence nothing is gained, and heat accumulates in the bearing as before. This important fact is verified by the design of high-speed bearings, which, it is always noted, are very long in proportion to their diameter, thus giving relatively high radiating power.

Bearings must be rigidly fastened to the body of the machine in some way, and the immediate support is termed a **bracket, frame, or housing.** "Bracket" is a very general term, and applies to the supports of other machine parts besides "bearings." It is especially applicable to the more familiar types of bearing supports, and is here introduced to make the analysis complete.

The bracket must be strong enough as a beam to take the side load, the bending moment being figured at such points as are necessary to determine its outline. It may be of solid, box, or ribbed form, the latter being the most economical of material, and usually permitting the simplest pattern. The fastening of the bracket to the main body of the machine must be broad to give stability; the bolts act partly in shear to keep the bracket from sliding along its base, and partly in tension to resist its tendency to rotate about some one of its edges, due to the side pull of the belt, gear tooth, or lever load, as the case may be. The weight of the bracket itself and of the parts it sustains through the bearing, has likewise to be considered; and this acts, in conjunction with the working load on the bearing, to modify the direction and magnitude of the resultant load on the bracket and its fastening.

Stands are forms of brackets, and are subject to the same analysis. The distinction is by no means well defined, although we usually think more readily of a stand as having an upright or inverted position with reference to the ground. The ordinary "hanger" is a good example of an inverted stand; and the regular "floor stand," found on jack shafts in some power houses, is an example of the general class.

THEORY. As the method of calculation of the diameter of the shaft, as well as its deflection, has been considered under "Shafts," we may assume that the theoretical study of bearings starts on a given basis of shaft diameter D. The main problem then being one of heat control, let us first calculate the amount of heat developed in a bearing by a given side load. The force of friction acts at the circumference of the shaft, and is equal to the coefficient of friction times the normal force; or, for a given side load P, Fig. 75, the force of friction would be μP. The peripheral speed of the shaft for N revolutions per minute is $\frac{\pi DN}{12}$ feet per minute. As work is "force times distance," the work wasted in friction is then $\frac{\mu P \pi DN}{12}$ foot-pounds per minute. One horse-power being equal to 33,000 foot-pounds per minute, we have the equation,

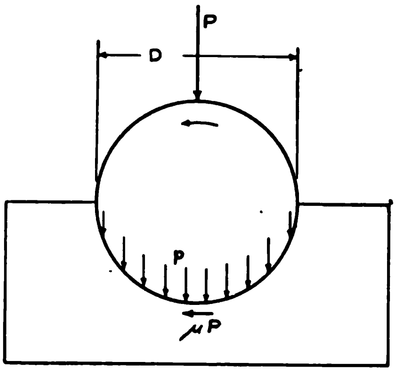


Fig. 75.

$$H = \frac{\mu P \pi DN}{12 \times 33,000}. \qquad (113)$$

The value of μ for ordinary, well-lubricated bearings, may run as low as 5 per cent; but as the lubrication is often impaired, it quite commonly rises to 10 or 12 per cent. A value of 8 per cent is a fair average. This amount of horse-power is dissipated through the bearing in the form of heat. If we could exactly determine the ability that each particle of the metal around the shaft had to transmit the heat, or to pass it along to the outside of the casting, and if we could then determine the ability of the particles of air surrounding the casting to receive and carry away this heat, we could calculate just such proportions of the bearing and its casing as would never choke or retard this free transfer of heat away from the running surface.

Such refined theory is not practical, owing to the complicated shapes and conditions surrounding the bearing. The best that we can do is to say that for the usual proportions of bearings the side load may exist up to a certain intensity of "pressure per square inch of projected area" of bearing, or, in form of an equation,

$$P = pLD. \tag{114}$$

The constant p is of a variable nature, depending on lubrication, speed, air contact, and other special conditions. For ordinary bearings having continuous pressure in one direction, and only fair lubrication, 400 to 500 is an average value. When the pressure changes direction at every half-revolution, the lubricant has a better chance to work fully over the bearing surface, and a higher value is permissible, say, 500 to 800. In locations where mere oscillation takes place, not continuous rotation, and reversal of pressure occurs, as on the cross-head pin of a steam engine, p may run as high as 900 to 1,200. On the crank pins of locomotives, which have the reversal of pressure, and the benefit of high velocity through the air to facilitate cooling, the pressures may run equally high. On the eccentric crank pins of punching and shearing machines, where the pressure acts only for a brief instant and at intervals, the pressure ranges still higher without any dangerous heating action.

When a bearing, for practical reasons, is provided with a cap held in place by bolts or studs, the *theory* of the cap and bolts is of little importance, unless the load comes directly against the cap and bolts. Except in the latter case, the proportions of the cap and the size of the bolts are dependent upon general appearance and utility, it being manifestly desirable to provide a substantial design, even though some excess of strength is thereby introduced.

For the worst case of loading, however, which is when the cap is acted upon by the direct load, such as P in Fig. 76, we have the condition of a centrally loaded beam supported at the bolts. It is probable that the beam is partially fixed at the ends by the clamping of the nut; also that the load P, instead of being concentrated at the center, is to some extent distributed. It is hardly fair to assume the external moment equal to $\frac{Pa}{8}$ or $\frac{Pa}{4}$, the one being too small, perhaps, and the other too large. It will be reasonable to take the external moment at $\frac{Pa}{6}$, in which case, equating the external moment to the internal moment of resistance,

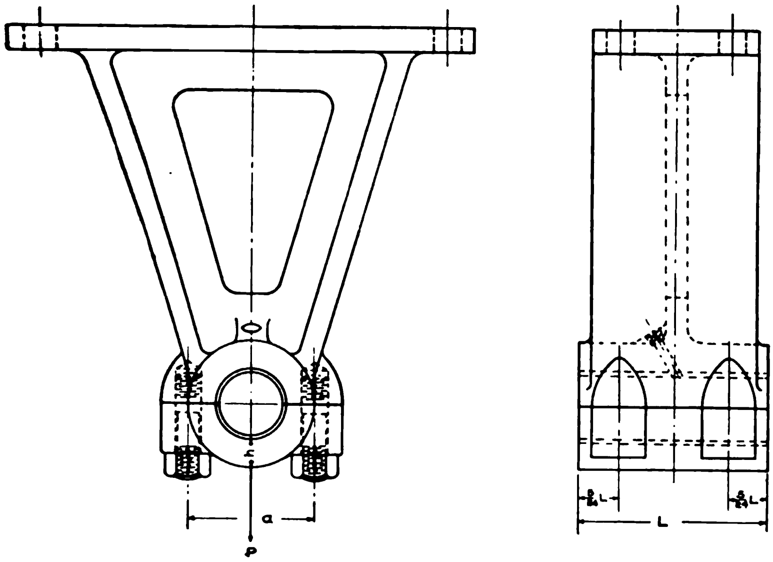


Fig. 76.

$$\frac{Pa}{6} = \frac{SI}{c} = \frac{SLh^2}{6}, \qquad (115)$$

from which, the length of bearing being known, we may calculate the thickness h.

One bolt on each side is sufficient for bearings not more than 6 inches long, but for longer bearings we usually find two bolts on a side. The theoretical location for two bolts on a side, in order that the bearing may be equally strong at the bolts and at the center of the length, may be shown by the principles of mechanics to be $\frac{5}{24}$ L from each end, as indicated in Fig. 76.

The bolts are evidently in direct tension, and if equally loaded would each take their fractional share of the whole load P. This is difficult to guarantee, and it is safer to consider that $\frac{2}{3}$ P may be taken by the bolts on one side. On this basis, for total number of bolts n, equating the external force to the internal resistance of the bolts, we have :

$$\frac{2}{3}P=\frac{S\pi d_1^2}{4}\times\frac{n}{2}, \qquad (116)$$

from which the proper commercial diameter may be readily found.

The bracket may have the shape shown in Fig. 77. The portion at B is under direct shearing stress; and if A be the area at this point, and S_s the safe shearing stress, then, equating the external force to the internal shearing resistance,

$$P=AS_s. \qquad (117)$$

The same shear comes on all parts of the bracket to the left of the load, but there is an excess of shearing strength at these points.

At the point of fastening, the bolts are in shear, due to the same load, for which the equation is

$$P=\frac{\pi d^2}{4}n_1S_s. \qquad (118)$$

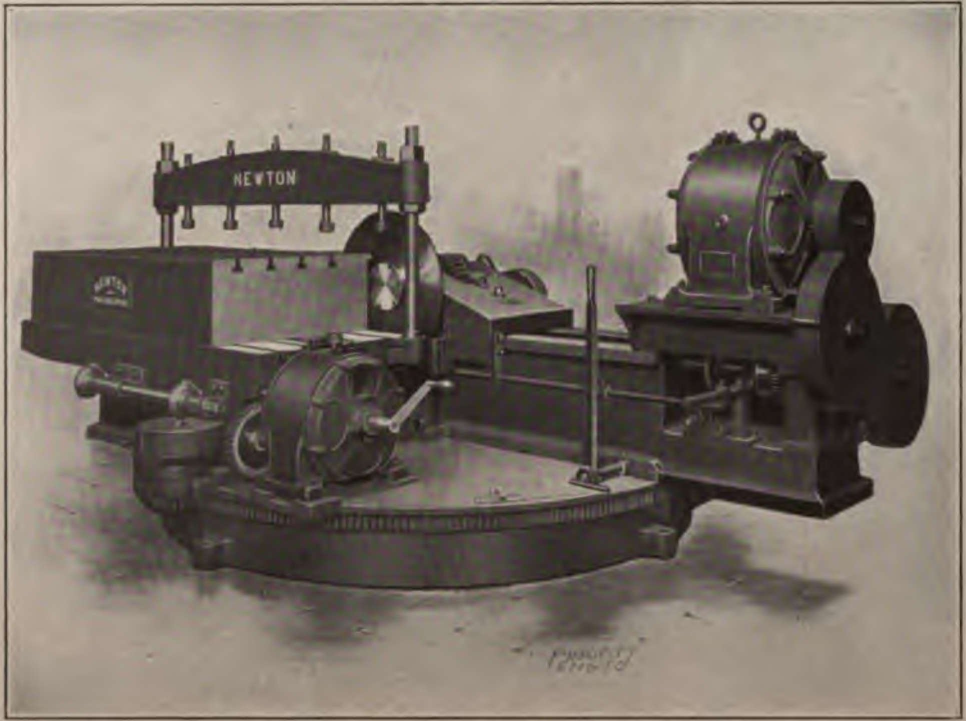
For the upper bolts, the case is that of direct tension, assuming that the whole bracket tends to rotate about the lower edge E. To find the load T on these bolts, we should take moments about the point E, as follows:

$$PL_1=Tl;\text{ or }T=\frac{PL_1}{l}. \qquad (119)$$

Then, equating the external force to the internal resistance,

$$T=\frac{PL_1}{l}=\frac{\pi d_1^2}{4}\times\frac{n_1}{2}S. \qquad (120)$$

The upper flange is loaded with the bolt load T, and tends to break off at the point of connection to the main body of the bracket, the external moment, therefore, being Tr. The section of the flange is rectangular; hence the equation of external and internal moments is:



WESTINGHOUSE TYPE C INDUCTION MOTORS DRIVING NEWTON COMBINED COLD SAW CUTTING-OFF MACHINE

$$Tr = \frac{PL_1}{l} r = \frac{Sbt^2}{6}. \qquad (121)$$

It may be noted that the lower bolts act on such a small leverage about E, that they would stretch and thus permit all the load to be thrown on the upper bolts; this is the reason why they are not subject to calculation for tension.

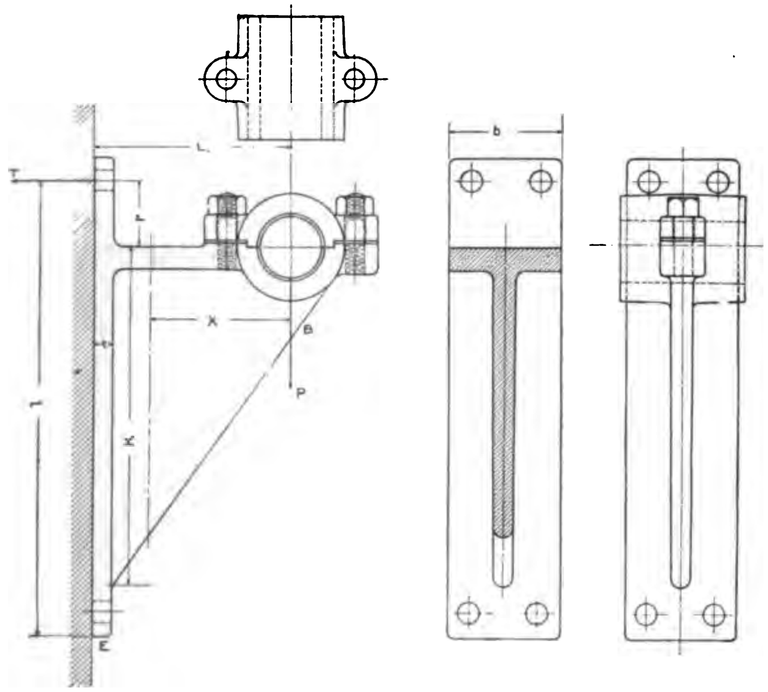


Fig. 77.

The section of the bracket to the left of the load P is dependent upon the bending moment, for, if this section is large enough to take the bending moment properly, the shear may be disregarded. It should be calculated at several points, to make sure that the fiber stress is within allowable limits. The general expression for the equation of moments is, for any section at leverage x,

$$Px = \frac{SI}{c}, \qquad (122)$$

from which, by the proper substitution of the moment of inertia of the section, the fiber stress can be calculated. The moment of inertia for simple ribbed sections can be found in most handbooks. The process of solution of the above equation, though simple, is apt to be tedious, and is not considered necessary to illustrate here.

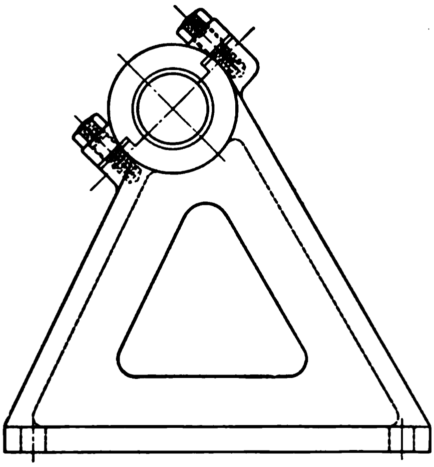


Fig. 78.

PRACTICAL MODIFICATION. Adjustment is an important practical feature of bearings. Unless the proportions are so ample that wear is inappreciable, simple and ready adjustment must be provided. The taper bushing, Fig. 79, is neat and satisfactory for machinery in which expense and refinement are permissible. This is true of some machine tools, but is not true of the general "run" of bearings. The most common form of adjustment is secured by the plain cap (which may or may not be tongued into the bracket), with liners placed in the joint when new, which may subsequently be removed or reduced so as to allow the cap to close down upon the shaft. Several forms of cap bearings are illustrated in Figs. 80, 81, and 82.

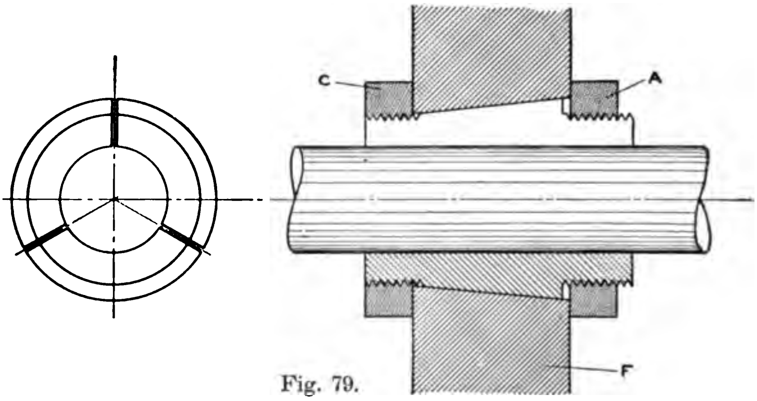


Fig. 79.

Large engine shaft bearings have special forms of adjustment by means of wedges and screws, which take up the wear in all directions, at the same time accurately preserving the alignment of the shafts; but this refinement is seldom required for shafts of ordinary machinery.

In cases where the cap bearing is not applicable, a simple bushing may be used. This may be removed when worn, and a new one inserted, the exact alignment being maintained, as the outside will be concentric with the original axis of shaft, regardless of the wear which has taken place in the bore.

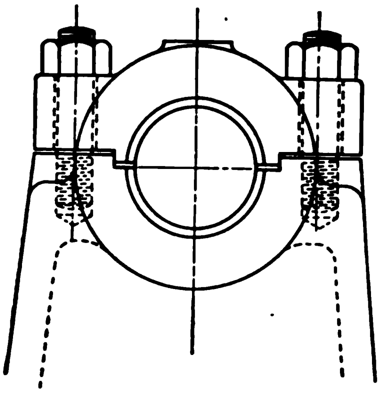


Fig. 80.

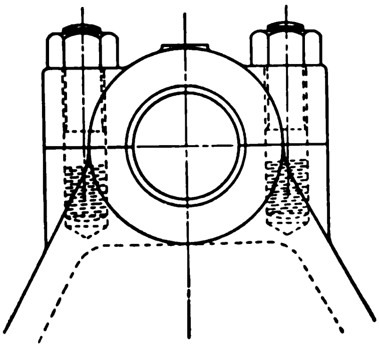


Fig. 81.

The lubrication of bearings is a part of the design, in that the lubricant should be introduced at the proper point, and pains taken to guarantee its distribution to all points of the running surface. The method of lubrication should be so certain that no excuse for its failure would be possible. Grease is a successful lubricator for heavy loads and slow speeds, oil for light loads and high speeds.

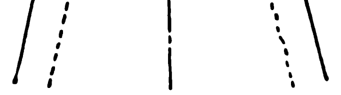


Fig. 82.

In order to insure the lubricant reaching the sliding surfaces and entering between them, it must be introduced at a point where the p sure is moderate, and where the motion of the parts will naturally lead it to all points of the bearing. Grooves and channels of ample size assist in this regard. A special form of bearing uses a ring riding on the shaft to carry the oil constantly from a small reservoir beneath the shaft up to the top, where it is distributed along the bearing and finally flows back to the reservoir and is used again.

The materials of which bearings are made vary with the service required and with the refinement of the bearing. Cast iron makes an excellent bearing for light loads and slow speeds, but it is very apt to "seize" the shaft in case the lubrication is in the least degree impaired. Bronze, in its many forms of density and hardness, is extensively used for high-grade bearings, but it also has little natural lubricating power, and requires careful attention to keep it in good condition.

Babbitt, a composition metal, of varying degrees of hardness, is the most universal and satisfactory material for ordinary bearings. It affords a cheap method of production, being poured in molten form around a mandrel, and firmly retained in its casing or shell through dovetailed pockets into which the metal flows and hardens. It requires no boring or extensive fitting. Some scraping to uniform bearing is necessary in most cases, but this is easily and cheaply done. Babbitt is a durable material, and has some natural lubricating power, so that it has less tendency to heat with scanty lubrication than any of the materials previously mentioned. Almost any grade of bearing may be produced with babbitt. In its finest form the babbitt is hammered, or pened, into the shell of the bearing, and then bored out nearly to size, a slightly tapered mandrel being subsequently drawn through, compressing the babbitt and giving a polished surface.

A combination bearing of babbitt and bronze is sometimes used. In this the bronze lies in strips from end to end of the bearing, and the babbitt fills in between the strips. The shell, being of bronze, gives the required stiffness, and the babbitt the favorable running quality.

PROBLEMS ON BEARINGS, BRACKETS, AND STANDS.

1. The allowable pressure on a bearing is 300 pounds per

square inch of projected area. What is the required length of the bearing if the total load is 4,500 pounds and the diameter is 3 inches?

2. The cross-head pin of a steam engine must be 2.5 inches in diameter to withstand the shearing strain. If the maximum pressure is 10,000 pounds, what length should be given to the pin?

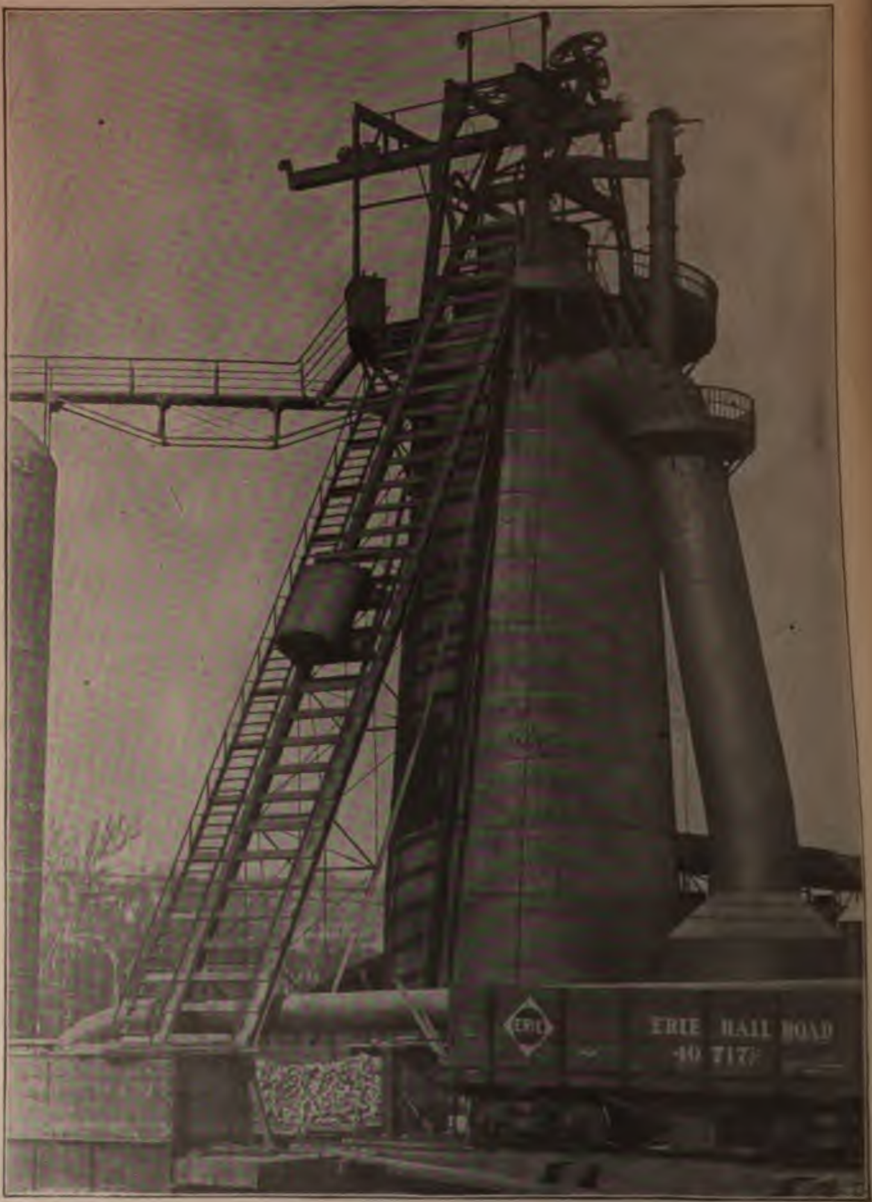
3. The journals on the tender of a locomotive are $3\frac{1}{2} \times 7$ inches. The total weight of the tender and load is 60,000 pounds. If there are 8 journals, what is the pressure per square inch of projected area?

4. What horse-power is lost in friction at the circumference of a 3-inch bearing carrying a load of 6,000 pounds, if the number of revolutions per minute is 150 and the coefficient of friction is assumed to be 5 per cent?

5. The cast-iron bracket in Fig. 77 has a load P of 1,000 pounds. Determine the fiber stress in the web section at the base of the bracket if the thickness is taken at $\frac{1}{2}$ inch, and $L_1 = 12$ inches; $l = 20$ inches; $k = 11$ inches; $t = 1$ inch.

6. Calculate the diameter of the bolts at the top of the bracket.

7. Assuming r equal to 6 inches, what is the fiber stress at the root of flange?



AUTOMATIC FURNACE HOIST
For Feeding Ore and Limestone to Blast Furnaces.

METALLURGY.

IRON.

For centuries iron has been the most useful metal known to man. In the earliest periods of history, stone implements were used; later bronze, an alloy of copper and tin, replaced stone. After a time men found a way to extract iron from its ores, and the Iron Age began. As nothing has yet been discovered, or invented, to take the place of iron in the arts, the Iron Age has continued until the present day. The process of separating, or extracting iron from its ores; of smelting and refining it; and of making it into its most useful form, steel, is called the metallurgy of iron. From small beginnings, this art has gradually increased to its present importance.

ORES.

Iron is never found pure; it is always compounded with other elements or minerals. These compounds, called ores of iron, occur in enormous quantities, and are widely distributed in the earth. The value of an ore depends upon its richness, its locality, the ease with which it can be smelted, and its freedom from phosphorus and sulphur. The principal ores are:

Magnetite, magnetic iron ore (Fe_3O_4). It is black, heavy and crystalline. The finest quality is found in Sweden, and sometimes contains as high as 72 per cent metallic iron. This ore usually contains from 40 per cent to 60 per cent metallic iron. A high temperature is required to reduce it.

Hematite, oxide of iron (Fe_2O_3). A red ore containing about 70 per cent of iron when pure; it is sometimes called "Hard Ore." About 82 per cent of all the ore now mined in the United States is red hematite.

Limonite, or brown hematite ($2Fe_2O_3\ 3H_2O$). Contains water which can be expelled by heat, leaving the ore of a reddish

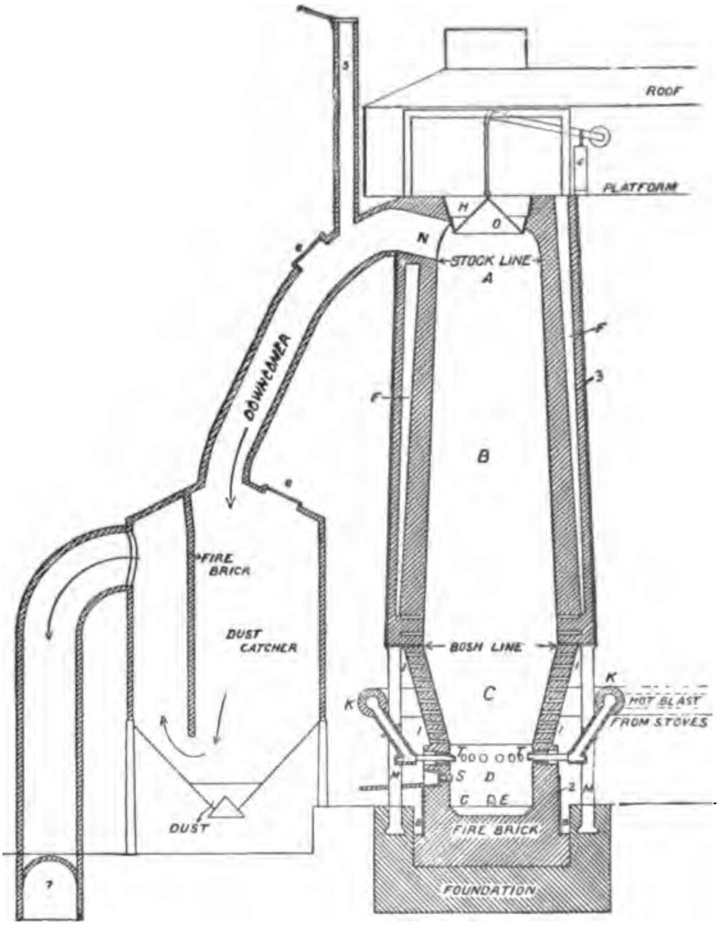


Fig. 1.

1. BRONZE COOLING PLATES.
2. CRUCIBLE JACKET.
3. SHELL.
4. BELL CYLINDER.

BLEEDER.
EXPLOSION DOORS.
7. FLUE LEADING TO STOVES AND BOILERS
8. DITCH FOR WATER.

HEIGHT,	90 FEET.	DIAMETER AT STOCK LINE,	15 FEET.
DIAMETER AT BOSH LINE,	20 FEET.	HEIGHT OF TUYERE CENTER,	8 FEET.
DIAMETER AT CRUCIBLE	13 FEET.	CAPACITY,	400 TONS PER DAY.

color. When pure this ore contains about 60 per cent of iron, and from 8 per cent to 20 per cent of water.

Siderite, or carbonate ($FeCO_3$) or ($FeOCO_2$). This is an important ore in Europe, although containing only about 48 per cent iron. It requires careful preliminary roasting before smelting.

Iron ores are never found pure ; they contain varying quantities of silica, alumina, calcium, manganese, sulphur and phosphorus.

MINERALS.

The principal minerals used in iron smelting are:

Iron Pyrites or fool's gold (FeS_2). It occurs in cubic crystals and bright shining scales. This mineral is used as a source of sulphur in the manufacture of sulphuric acid. In some cases it is smelted for iron after its sulphur has been used.

Franklinite, or oxides of iron, manganese and zinc ($FeO\ MnO\ ZnO$) ($Fe_2O_3Mn_2O_3$). It contains about 46 per cent of iron. It is used in the manufacture of zinc white and spiegeleisen. "Spiegel," is a coarsely crystalline variety of cast iron, with large crystal planes having bright reflections. It usually contains about five per cent of combined carbon and 10 per cent to 20 per cent of manganese.

Limestone, *Chalk* or *Oyster Shells*, — carbonate of calcium ($CaCO_3$). Used as a flux.

Dolomite, carbonate of calcium and magnesium [$(Ca\ Mg)CO_3$], sometimes substituted for limestone.

PREPARATION OF ORES.

Usually the ore is broken into small pieces and then reduced to metallic iron in the blast furnace. Sometimes it is broken into small pieces, piled up, and exposed to the air and rain. By this means dirt, sand and soft rock are washed out. In this country iron ore is seldom roasted, but when necessary it is roasted in kilns, thus driving out the sulphur.

THE BLAST FURNACE.

The blast furnace is located in a place where materials may be economically assembled, product cheaply transported to market, and a good water supply is available.

The blast furnace is a circular brick or stone structure, lined with fire brick and encased in sheet iron. The general arrangement is shown in Fig. 1. The throat at A is about 15 feet in diameter; the main portion B, called the shaft, is nearly cylindrical and about 60 feet high and 20 feet in diameter. The lower portion C, which is shaped like an inverted frustum of a cone, is called the boshes and is about 20 feet high and 14 feet in diameter in the smallest part. Below the boshes a cylindrical portion D, called the hearth, extends about 10 feet and is lined with fire brick. This total h feet, but some are over 100 feet high. The tuyeres number, are pipes through which hot blasts of air ar nd are built into the brickwork about 6 feet above f the hearth. The tuyeres are made as simple as possi nstructed so that they may be easily taken out and repla bustle pipe K, supplies air to the tuyeres. The part o G, below the tuyeres is called the crucible, which being subjected to intense heat, is often cooled by water flowing through a series open gutters around it. The boshes are kept cool by water circu ing through a series of cooling rings, cast in bronze block set in the brick or masonry walls.

There are two openings in the crucible wall; the upper, called the cinder notch for the removal of slag or "cinder," and the lower for the molten cast iron. The upper or "slag eye" S, is stopped up by an iron plug on a long handle; but the lower or "tap hole" E must be plugged with clay. Balls of clay are rammed in and soon baked as hard as stone by the heat. For large furnaces a "gun" is used to force the clay balls into the hole. This clay is two or three feet in thickness and when the iron is ready to flow out it is drilled. The work of drilling through this clay is considerable, and in modern furnaces is done by a steam tapping hole drill.

Just above the throat is the bell O and hopper H (Fig. 1). The materials are placed in the hopper and dumped into the throat of the furnace, by lowering the bell. The bell is raised and lowered by levers and counter-weights, operated by steam or compressed air.

The gases leave the top of the furnace just below the bell at

N; they pass through a dust catcher and then go to the stoves and boilers to be used as fuel. The stoves are used to heat the air for the tuyeres, and the boilers furnish steam for the blowing engines and hoisting engines.

The columns M support the weight of the furnace. The whole rests on the masonry foundation. The space F, called the expansion space, allows for the expansion of the inner wall; it is sometimes packed with granulated slag.

MATERIALS.

The materials used in the blast furnace are:

Ores, already briefly described.

Fluxes. Flux is the substance added to combine with the earthy impurities and make a fusible slag which floats on the molten iron. The impurities which would soon clog up the furnace, are thus removed. Limestone and Dolomite are the usual fluxes. Oyster shells are used in Maryland on account of cheapness.

Fuels. The fuels used are coke, which is made in beehive ovens from soft coal; charcoal, which is wood charred in heaps or kilns; anthracite coal, and very rarely bituminous coal.

The fuel depends largely upon the locality. Charcoal is a good blast furnace fuel on account of its porosity, slight ash, and freedom from sulphur. Coke is the best fuel because it is strong enough to resist being crushed by the great weight of materials and because it burns rapidly thus giving a large output. Anthracite coal breaks up very fine and burns to CO slowly. A good mixture is ¼ coke and ¾ anthracite coal. Bituminous coal is rarely used as it cakes and absorbs heat.

OPERATION OR RUNNING.

Blowing in. To start the blast furnace it is first thoroughly dried and then filled with cord wood to about half-way up the boshes. Upon this is placed a blank charge of coke, and then successive layers of fuel, flux and ore, with gradually increasing amounts of ore, until the regular charge is reached. The wood is then lighted and the hot blast of air turned on. At first this blast is under slight pressure. When coke is used the iron begins to flow in about 15 to 20 hours after lighting.

The ore, fuel and flux are brought to the scales in barrows called buggies. They are then weighed and wheeled to the elevator, and a certain number of barrows of each dumped into the hopper. In many large furnaces self-dumping cars are run to the top on an inclined railway, and the charging is entirely automatic. The fuel charge is usually dropped in by itself, followed by the ore and flux. The level of stock in the furnace is kept constant by regulating the charges. The temperature of the blast is kept as nearly constant as possible, being regulated by the admission of cold air. Cold water is kept running through the cooling rings around the bosh walls. Slag is either drawn off at intervals or continuously, and the molten iron which collects in the crucible, is drawn off every four to six hours by drilling the tap hole. It runs into channels formed in sand; the main channel is called the sow, and the smaller ones branching from it, the pigs. When solid the pigs are broken apart and stacked ready for transportation. The latest development in pig casting is an apparatus consisting of an endless iron mould which revolves and receives the charge and discharges the cooled pigs on the cars.

The furnace is run continuously day and night until it is necessary to shut down for repairs. Sometimes furnaces are run continuously for three to five years.

A good-sized blast furnace using coke as a fuel, will produce 300 tons of pig iron every twenty-four hours, and some of the largest can turn out 600 tons.

BANKING THE FURNACE.

It is sometimes necessary to shut down the furnace, because of a falling market, a flood, or a strike. If it is to be banked at a moment's notice, the first thing to do is to tap out the metal, shut off the blast and the water jackets; then close the furnace so that there will be no draft through the shaft. The tuyeres are blanked by ramming in clay balls. In this case the blast should be resumed in two or three weeks. If there is time to plan the shutting down, a large charge of fuel is dumped in and successive charges containing an increasing proportion of ore. The blast is shut off when the fuel reaches the tuyeres; the bell sealed and the cooling water decreased. The blast need not be resumed in this case for four or five months.

To blow out for repairs, stop the ore charges, and continue to charge fuel with a small amount of flux until the flow of metal ceases.

THE CHEMISTRY OF THE FURNACE.

In the blast furnace the oxides of iron give up their oxygen and become metallic iron. The most important substance for effecting this change is carbon monoxide CO. As we learned in Chemistry, CO gas has an affinity for oxygen, tending to form CO_2.

At the tuyeres the carbon burns to CO. Near the top of the furnace, at a temperature of 400° to 600° F, this CO reduces the iron ore (Fe_2O_3) to metallic iron, thus

$$Fe_2O_3 + 3CO = 2Fe + 3CO_2.$$

The iron is not melted here, but is in a pasty condition. The charge gradually descends, getting hotter and hotter. At the boshes it is at a bright red heat, and in the lower part the iron begins to melt, and the lime, silica and other earthy materials fuse and form slag. At this point part of the silicon, manganese, sulphur and phosphorus are reduced, and together with a little carbon, combine with the iron. In the crucible all is melted and the temperature is above 2200° F.

SLAG.

The earthy materials, silica, alumina, and sulphur of the ore and fuel, combine with the flux, and form the slag. A large part of the sulphur is then eliminated from the ore; but none of the phosphorus. The quality of the iron depends largely on the composition of the slag. If a high lime slag is used in order to reduce the sulphur and silicon in the pig iron, there is danger that the slag may not run well, in which case more alumina is used. A good slag has approximately the following constituents: 52 per cent $CaO + MgO$, 16 per cent Al_2O_3 and 32 per cent SiO_2.

STOVES.

In the first blast furnaces cold air was used for the blast. Stoves were introduced to effect a saving of fuel and to increase the out-put. The waste gases from the blast furnace contain about 25 per cent of carbon monoxide, CO, and 1 per cent of hydrogen, H. These gases are burned with air in brick stoves and the fire brick flues are heated to redness. Then the cold air blast is run through and is heated to above 1000°F.

Four stoves are generally used in a set, three being heated while the fourth is giving out heat to the blast. The fuel consumption with a hot blast is about one-half that with a cold blast.

CAST IRON.

The iron produced by a blast furnace, known as cast iron or pig iron, is impure. It contains carbon, phosphorus, sulphur, silicon, manganese, and traces of other elements.

Cast iron is brittle, fusible and cannot be welded. It melts at a temperature of 2100°F. to 2300°F. Gray iron is more fluid when melted, and not as brittle as white iron.

Cast iron is suitable for castings because it expands at the moment of solidifying; this expansion is due to the change in the position of the crystals and results in a sharp impression of the mould. The casting is smaller than its pattern because the shrinkage in cooling from a red hot solid is greater than the expansion at the moment of solidification. If iron moulds are used, the surface of the casting becomes chilled, which causes a harder surface.

The Tensile Strength of cast iron is 13,000 — 29,000 pounds per square inch; Compressive Strength 82,000 — 145,000 pounds per square inch; Modulus of Elasticity 14,000,000 to 22,000,000.

Pig Iron is sometimes graded according to its fracture. This method is satisfactory if the irons are made from uniform ores and mixture of fuels; but is unreliable if the irons are produced in different sections of the country, or from different ores. Grading by chemical analysis is better. There are five standard grades according to hardness.

No. 1. Gray. Fracture rough. It is dark, open grain and the softest grade. Used exclusively in foundry work. Tensile Strength low. Elastic Limit low. Turns soft and tough.

No. 2. Gray. Mixed grain. Harder than No. 1. Fracture less rough, with higher Tensile Strength and Elastic Limit than No. 1. Used in foundry. Turns harder, less tough and more brittle than No. 1.

No. 3. Gray. Close grain. Used in foundry and rolling mill. Turns harder and less tough than No. 2.

No. 4. Mottled. Dotted with small black dots of graphite. Little

rain. Used in rolling mill. Lower Tensile Strength and Elastic Limit han No. 3.

No. 5. White, no grain, smooth fracture. Used in the Bessemer rocess and in the rolling mill. Tensile Strength and Elastic Limit lower han No. 4. Too hard to turn and very brittle.

The following table gives average analyses of the various grades of cast iron, the amounts being given as per cents:

Grade Number.	Iron.	Graphitic Carbon.	Combined Carbon.	Silicon.	Phosphorus.	Sulphur.	Manganese.
1	92.37	3.52	.13	2.44	1.25	.02	.28
2	92.31	2.99	.37	2.52	1.08	.02	.72
3	94.66	2.50	1.52	.72	.26	Trace	.34
4	94.48	2.02	1.98	.56	.19	.08	.67
5	94.68	——	3.83	.41	.04	.02	.98

INFLUENCE OF CARBON, SILICON, PHOSPHORUS, SULPHUR AND MANGANESE.

Carbon. The state of the carbon in the pig iron is a most important factor in the quality. If the carbon is combined with the iron in the form of an alloy, a hard, brittle, white iron is produced. If it is present mainly as graphite distributed as small crystals throughout the entire mass, the iron is soft and gray in color, but not as strong as white iron. Gray iron expands more on solidifying and contracts less in cooling than white iron.

Silicon. The amount of silicon and the rate of cooling determine the proportion of graphitic to combined carbon in the casting. Increasing the silicon in cast iron increases the proportion of graphitic carbon, thus making the iron softer. A large quantity of silicon renders the iron stiff and weak.

Phosphorus. Phosphorus in general weakens cast iron, but it is not harmful if less than 1 per cent is present. In some cases phosphorus is beneficial, as it decreases shrinkage and increases fluidity. For small, thin castings, iron may contain a little over 1 per cent phosphorus.

Sulphur. Sulphur makes castings hard and unsound. It also prevents the iron from flowing well. The amount of sulphur should not be over .5 per cent for sharp castings.

Manganese. Manganese in cast iron increases hardness and shrinkage and makes it more brittle. Manganese makes the iron capable of holding more carbon. Sometimes the amount of carbon is as high as 5 per cent, as in Spiegel.

Manganese with some chill is used in the foundry to produce hardness of surface. The magnetism of iron is decreased by manganese ; if 25 per cent is present all magnetism is lost.

CASTINGS.

In order to get a good casting, an iron having the following requisites should be used :

Shows gray fracture.
Is easily worked by tools.
Fills the mould to the thinnest parts.
Chills with a smooth surface.
Free from blow-holes.
Has moderate strength.
Little shrinkage.

An iron with the following constituents fills these conditions:

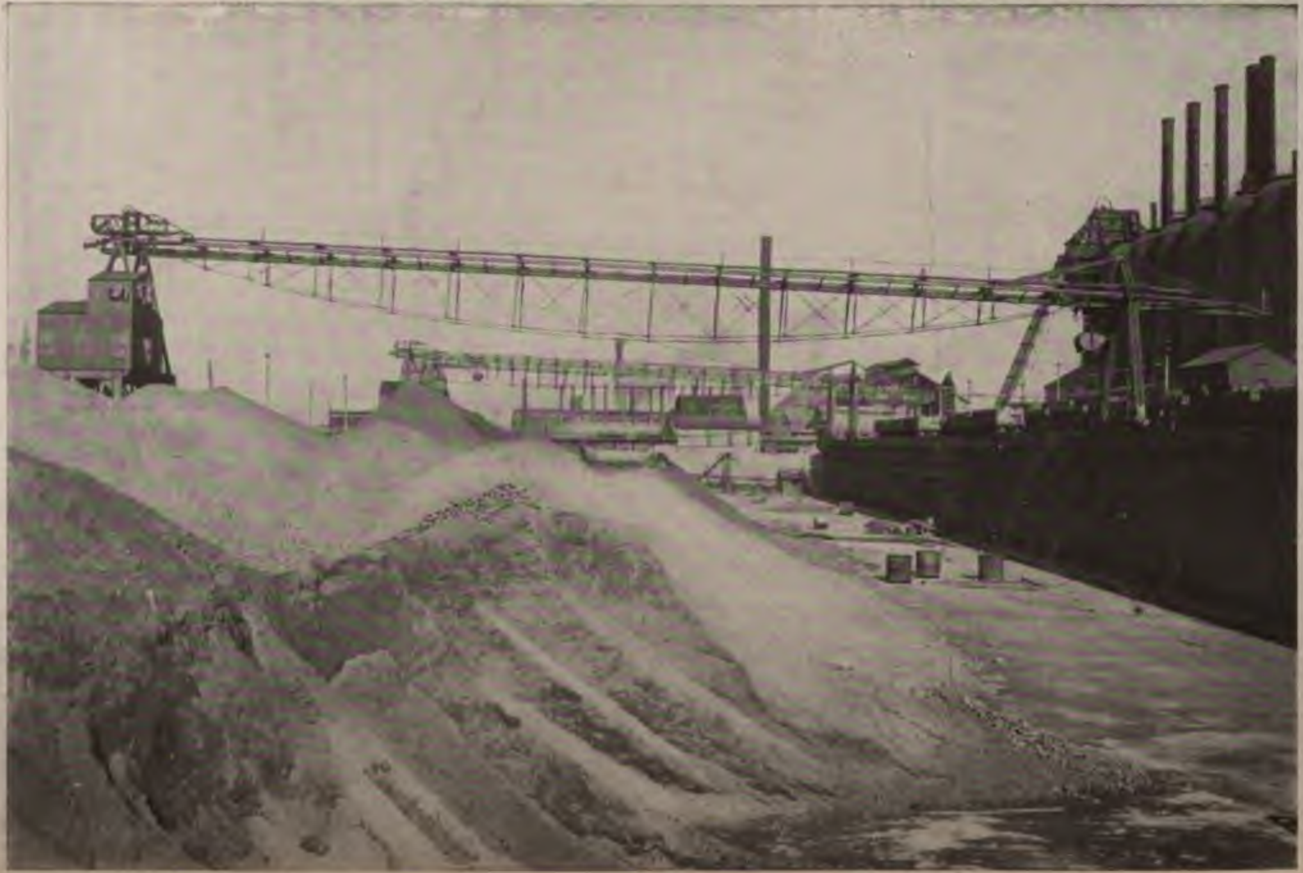
Carbon,	3½ per cent.
Silicon,	1½ per cent to 2 per cent.
Phosphorus,	not over .7 per cent.
Sulphur,	only a trace.
Manganese,	.35 per cent to .70 per cent.

For large castings lower the silicon. For increase in strength lower the carbon, silicon and avoid phosphorus. For resistance to chemical action make the manganese as high as brittleness will allow.

Silver-gray and ferro-silicon irons are used to increase silicon. Spiegel and ferro-manganese are used to increase manganese. Both wrought iron and steel scrap are used to reduce carbon.

MALLEABLE CAST IRON.

Malleable cast iron is a crude form of wrought iron obtained by decarbonization. The castings are made in the ordinary way from low silicon iron with little phosphorus and sulphur ; they are embedded in oxide of iron or peroxide of manganese and heated to a red heat until most of the carbon is removed from the



ORE-STORAGE AND REHANDLING PLANT.

Duquesne Furnaces, Carnegie Steel Co., Ltd.

surface. The time necessary for this operation is three to fourteen days, depending upon the size of the casting.

An analysis for good malleable iron is:

Si	.75 — 1.00 per cent.	P	.20 per cent.
S	below .05 per cent.	Mn	.40 to .75 per cent.

This wil be a No. 3 iron.

In making malleable castings, sharp angles and abrupt changes from heavy to light sections should be avoided. Several thin ribs in place of one thick rib should be used. As much surface as possible should be exposed, as the strength lies in the skin.

WROUGHT IRON.

Removing most of the carbon, silicon, phosphorus and manganese from pig iron makes it tough, malleable, harder to melt and capable of being welded. This iron is known as wrought iron, and is obtained by a process called puddling. The operation of making wrought iron from the ore is called a Direct Process. On account of its simplicity it was the first used.

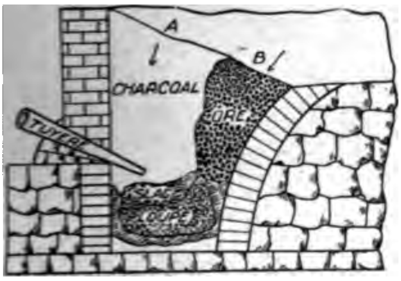


Fig. 2.

The Direct Processes are carried on at a low temperature; the production is small and variable, and about 20 per cent of the iron in the ore is lost. One of the oldest methods of making wrought iron directly from the ore is the Catalan Process. Ore of egg size is charged at B, Fig. 2, and charcoal at A. As the smelting progresses, charcoal and moist fine ore are charged at A. As the ore becomes reduced it works towards the tuyere; when it is all reduced it is taken out in a large lump called the "loupe" and worked under a hammer.

There are other processes, but they are unimportant and most all have been abandoned.

THE PUDDLING PROCESS.

The refining of pig iron by puddling converts it into wrought iron. This process is carried on in a reverberatory furnace. Fig. 3 shows sectional view of the plan and elevation.

The furnace has a low-arched roof and oval hearth H. The flame from the fire passes over the charge of iron, which is melted by the intense heat. The pig iron used in this process is gray and unrefined and has more silicon than white iron. The fettling or lining L of the hearth is made of good magnetite or hematite. The fettling is repaired after every heat.

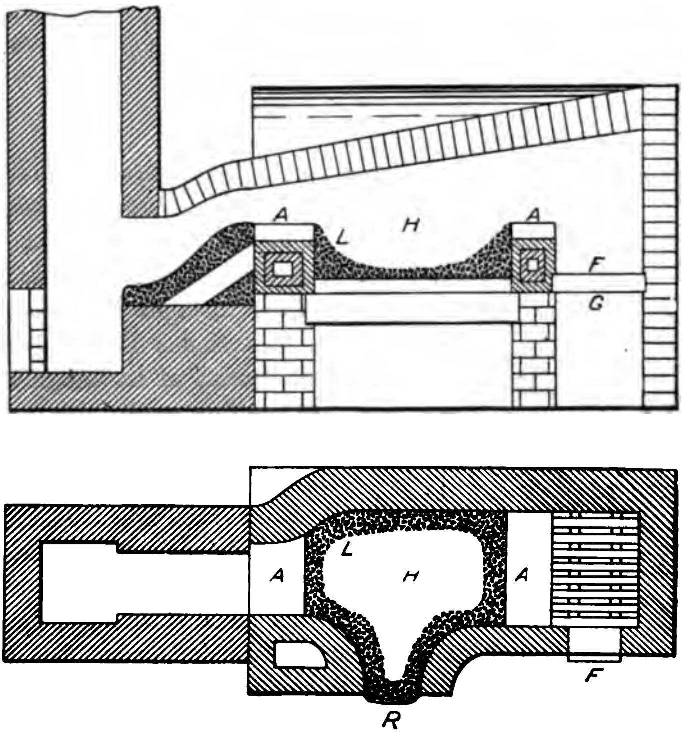


Fig. 3.

A. — BRIDGES.
F. — FIRE-DOOR

G. — GRATE.
R. — RABBING-DOOR.

Carbon, silicon, manganese, phosphorus and sulphur unite with oxygen from the hot blast and the iron ore lining, thus reducing the molten metal to wrought iron. In order that the whole of the metal may come in contact with the fettling it is stirred constantly by rods called "rabbles." It takes about thirty minutes to melt down, and then carbon begins to be oxidized to

CO gas, which makes a violent boiling for about 15 minutes. The silicon, manganese, etc., oxidize and form a slag. When all the carbon is boiled out, bright points appear and the iron becomes pasty. The iron is gathered into balls and then worked under the hammer and rolls to expel the slag. It is afterward reheated and rolled between grooved rollers, which causes the particles to become close together. If the bar is rolled once it is called muck bar; if cut up, heated and rolled again, merchant bar; the best bar iron is rolled a third time.

The Puddling Process and the manufacture of wrought iron is gradually giving way to mild steels; but because of the small amount of slag it contains between the fibres, which acts as a flux, wrought iron welds much easier than steel and is preferred by blacksmiths.

The Puddling Process is expensive on account of the large amount of fuel used in the production of metal. About one ton of fuel is necessary to produce one ton of muck bar. For this reason and on account of the expense of the mechanical work of puddling, many efforts have been made to produce a cheaper and more simple process.

Boilers have been mounted over the furnace to utilize the waste gases as fuel, but on account of the fluctuating heat of the furnaces they have not been entirely successful. Water-tube boilers mounted in this way have been the most satisfactory.

There are several contrivances to save fuel and labor, but as the mechanism is likely to get out of order, they are not always reliable. For saving of labor, the Dank's Puddling Furnace, Fig. 4, is the most efficient and satisfactory of the mechanical puddlers. It is shaped like a short barrel, lying on its side. It is supported by friction rollers, two at each end, and driven by a large gear G around its middle. In this furnace the revolving of the hearth takes the place of puddling or stirring by hand.

Iron ore worked in layers at low heat forms the fettling. It is fed with molten iron from a furnace by means of a ladle. In some places this furnace is used for ordinary puddling, and in others for making wrought iron for the Open-hearth and Siemens Processes for making steel.

Wrought iron contains from .5 per cent carbon to only a trace; as carbon decreases, malleability increases, and the melting point rises. The melting point of good wrought iron is about 3000°F.

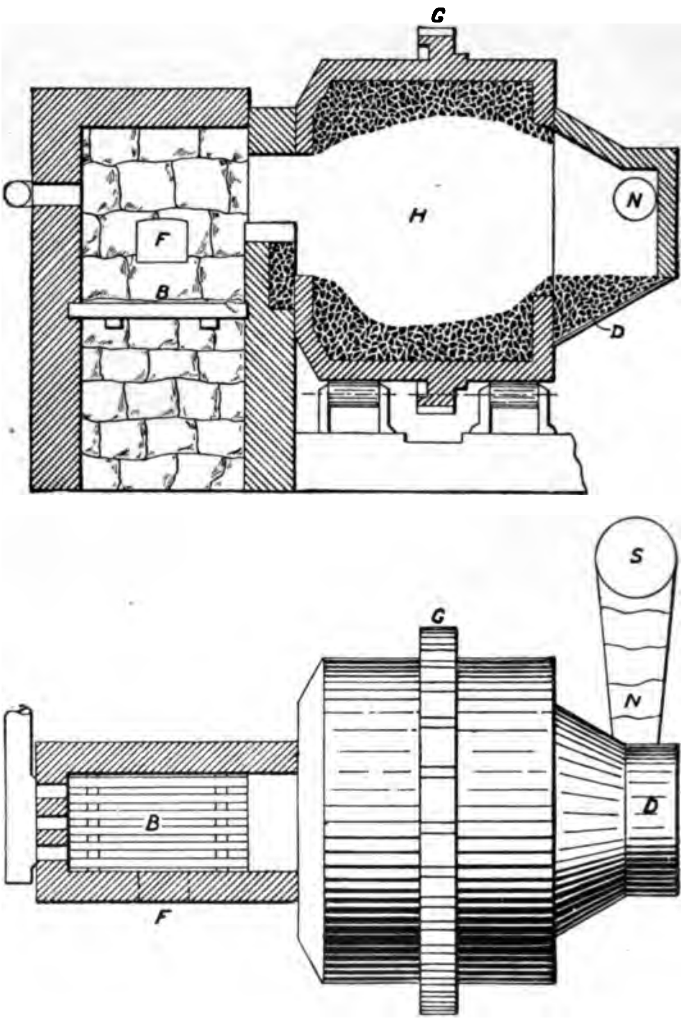


Fig. 4.

B — GRATE.
F — FIRE-DOOR.
H — HEARTH.
D — MOVABLE FLUE-PIECE.
N — FLUE TO STACK.
S — STACK.

Wrought iron contains about 2 per cent of slag distributed among the fibres. It is always present because the iron is finished in a pasty condition and the slag is never completely removed by the subsequent squeezing and rolling.

The fracture of wrought iron is coarsely fibrous, sometimes showing a few bright granular spots. The best iron is granular when broken suddenly.

The reduction of area of bars by rolling influences the strength and elastic limit. In general, the greater the reduction the higher the strength and elastic limit. Underheated bars have an unduly high tenacity and elastic limit.

The absolute strength of wrought iron is not materially altered by cold. The extensibility, or ductility, is not less in severe cold than at ordinary temperature. The modulus of elasticity rises as the temperature falls.

WELDING.

The process of welding consists of heating two pieces of iron to a high temperature, laying them together and hammering. Borax is sometimes sprinkled on the surfaces to be united, in order to keep them bright. This is accomplished by the union of borax with the oxide forming a fusible borate. In order that the form of the piece after welding may not be spoiled by hammering, the two ends to be joined are upset and scarfed. The upsetting makes the ends larger, so that they may be hammered without making the joint too small, and the scarfing roughens the ends, making the pieces join more easily.

STEEL.

CEMENTATION PROCESS.

Cement or blister steel is made from wrought iron by this simple process. The purest, soft wrought iron is heated to redness while completely covered with charcoal. The temperature is kept constant for over a week. The iron takes up some of the carbon from the charcoal and is converted into steel. It is called blister steel on account of its appearance, the surface being covered with small scales or blisters. These bars of blister steel are cut, heated and rolled together, forming shear steel. If the process is repeated, the product is called double shear steel.

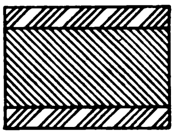
Blister steel that has been cut up, melted in a black-lead pot and cast in an ingot, is called cast or crucible steel.

The metal used in Sheffield, England, is wrought iron made from Swedish pig iron. Hammered wrought iron bars are laid in firestone pots in layers, surrounded with charcoal. At one end is placed a test bar, so arranged that it may be drawn out, examined, and returned. The temperature is gradually increased for 7 days to about 1150° F., and then the furnace is kept at this temperature for 7 or 8 days more. It takes 7 days for it to cool down.

When the bars are taken from the charcoal, the outside layers are converted into steel, leaving the center wrought iron. The use for which this steel is intended determines the amount of conversion; the various kinds are classified as follows:

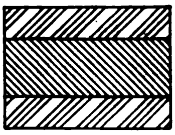
(1) Spring heat, .5 per cent C. Large iron center.

1



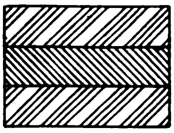
(2) Country heat, .63 per cent C. Smaller iron center.

2



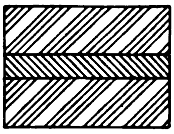
(3) Single shear heat, .75 per cent C. Equal iron and steel.

3



(4) Double shear heat, 1 per cent C. Mostly steel.

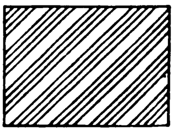
4



(5) Steel through heat, 1.25 per cent C. All steel.

(6) Melting heat, 1.5 per cent C. All steel.

5 AND 6



The reaction which takes place is

$$4Fe + 2CO = Fe_4C + CO_2.$$

CRUCIBLE PROCESS.

The materials are bar iron with charcoal, puddled bar or blister steel and charcoal. The crucibles are made of clay or graphite, with a capacity of 50 to 85 pounds. The charge is put into the crucible, and after melting is allowed to stand for a time, called the killing period, and then poured into moulds.

In American practice, graphite crucibles are used, which are made from a mixture of fire-clay and sand, and about 50 per cent graphite. This mixture is ground, allowed to stand for a few days, and is then moulded by being pressed into a wooden mould. When dry, it is baked in a kiln. These crucibles can be used about five times, if the successive charges are gradually diminished in amount.

The crucible is charged cold. The pieces of iron are surrounded with charcoal, with a little manganese, and sometimes a little salt or ferrocyanide of potassium mixed with it. This crucible, after being covered, is placed standing on the coal in a hot furnace. After three hours, during which the contents are melted, the cover is lifted, and the melter examines the charge to determine the length of the "killing" period. During this period, which is about 45 minutes, the metal is becoming tranquil and is taking silicon from the sand in the walls of the crucible. The silicon prevents blow-holes. At the right time and temperature the crucible is lifted out and the slag skimmed off. The metal is now ready for casting, or "teeming." This is done by pouring the metal into split moulds.

The ingots are graded and hammered into bars for different uses. Crucible steel furnishes the finest grades for cutlery and machine tools; it is superior to Bessemer and Open-hearth steel, because pure materials are used and the process is carried on in a closed vessel, thus protecting the metal from sulphur gases from the fuel.

It has low phosphorus, low sulphur, no iron oxide, less gases, high carbon and high silicon.

Crucible steels are graded as follows:

Razor. 1½ per cent C. Easily burned, very hard temper, welded with difficulty.

Saw-file. 1¼ per cent C Not easily burned, hard temper.

Tool. 1¼ per cent C. Not easily burned, hard temper, welded with difficulty.

Spindle. 1⅛ per cent C. Not easily burned, hard temper, welded with difficulty.

Chisel. 1 per cent C. Not easily burned, fair temper.

Set. ⅞ per cent C. Difficult to burn, little temper, easy to weld.

Die. ¾ per cent C. Difficult to burn, little temper, easy to weld.

THE BESSEMER PROCESS.

Bessemer, by his experiments, found that the temperature of molten metal was raised by blowing a current of air through it.

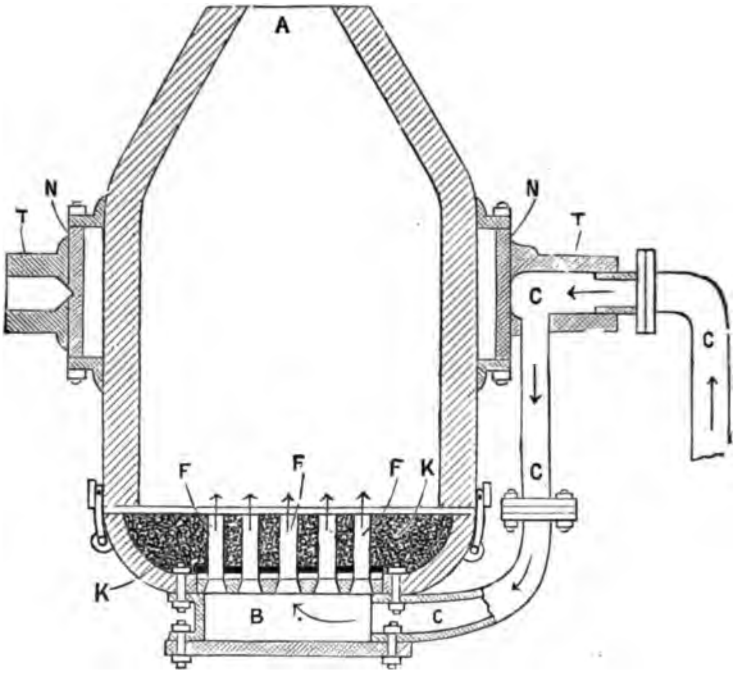


Fig. 5.

He tried to make wrought iron from pig iron, but found that the metal taken from the converter at that point was worthless; by restoring carbon by means of an alloy the product was better than wrought iron.

By this process steel is made from pig iron by burning out the foreign substances and replacing the necessary amounts of carbon, and manganese. These foreign substances — silicon, carbon and manganese — are burned out by blowing a blast of cold air through the molten pig. The desired amounts of carbon and manganese are replaced by mixing the proper proportion of spiegel with the molten pig.

The process is carried on, not in a furnace but in a vessel called a converter, in which molten pig is "converted" into steel.

There are several forms of converters. Fig. 5 shows a concentric converter. It is round, with a detachable flat bottom. The outer casing is of sheet iron. It is filled and emptied at the nose A. The current of cold air enters through the pipe C, and passes through the trunnion T. It enters the converter from the wind-box B, passing through the tuyeres F. The tuyeres are of fire brick 24 to 28 inches long, and have 19 holes $\frac{5}{16}$ inch in diameter, or 7 holes $\frac{3}{8}$ inch in diameter. The trunnion rings N are fastened to the converter, which turns on the trunnions T The bottom is coupled on with clamps.

The pig iron is not melted in the converter, but poured into it in a molten state.

There are two processes of working.

(1.) The Acid Bessemer.

(2.) The Basic Bessemer, or Thomas-Gilchrist.

The difference is in the lining of the converter. If this lining is acid (siliceous) no phosphorus or sulphur is burned out of the pig. Only irons with small amounts of these elements can be used in this process. If the lining is of lime or magnesia all the phosphorus and almost all of the sulphur can be burned out. Only a high phosphorus pig can be used in the basic process, as the heat needed to keep the steel liquid, during casting, is obtained from the phosphorus.

The Basic Process is used in Germany with good results.

In both processes the carbon, silicon, manganese, etc., are oxidized, leaving the molten iron in a condition similar to that of wrought iron. The carbon passes away as CO, and the oxides of silicon and manganese with a little iron oxide form a slag. Molten spiegel is added to give it the necessary carbon, and a little manganese to make it malleable. The molten pig is obtained in two ways; by melting the pig in cupolas, called the Cupola Process; and by taking the iron from the blast furnace, called the Direct Process.

THE CUPOLA PROCESS.

Pig iron, from piles which have been sampled and analyzed, is loaded into trucks and wheeled to the cupolas. The composition of this mixture is about as follows :

Silicon	1.75 per cent.
Manganese	.75 per cent.
Sulphur less than	.05 per cent.
Phosphorus less than	.10 per cent.
Copper less than	.10 per cent.

This is weighed, hoisted to the cupola and dumped in. Spiegel is sampled, analyzed and melted down in smaller cupolas. The fires in the cupola are started with wood upon which is placed coke; the charges of pig iron being dumped on the coke. It takes about two hours to melt the first charge. As some silicon burns out in the cupola the percentage is reduced. When the iron goes into the converter there must be from 1 to 2 per cent silicon present, depending on the temperature of the iron.

THE DIRECT PROCESS.

In the ordinary blast furnace, different casts differ too much in silicon and sulphur to allow taking the metal as it flows from the furnaces into the ladle and then to the converter. Therefore, it is first poured into large reservoirs or mixers, in which the casts from the different furnaces are mixed. In Sweden, however, the product from a number of small charcoal furnaces is regular enough for the iron to be used directly. The iron is taken from the mixers as wanted and used as cupola iron. If the iron stands in the mixer a long time some sulphur is eliminated, but no carbon or silicon. To prevent the iron from chilling on top, a jet of oil is sprayed over it. As the temperature of direct iron is greater than that of cupola iron, less silicon is needed.

Blowing. The heated bottom is coupled on and the joint rammed tight from the outside. When the lining is made yellow-hot by means of a fire of wood and coal with a gentle blast, the iron from the cupola or the mixer is poured in and the blast turned on.

The converter is turned up to a vertical position, as shown

. 6, as it is filled when turned down on its side. The blast
, up through the bath, and silicon begins to oxidize raising
emperature high enough for the carbon to burn. Carbon
s to CO. The blower judges whether there will be enough
to keep the steel liquid during the casting, by the appear-
of the flame which comes out of the throat of the converter.
e thinks there will not be enough heat, the converter is turned
f-way down and the CO burns to CO_2. Fig. 7 shows the
verter turned down until the tuyeres are exposed.

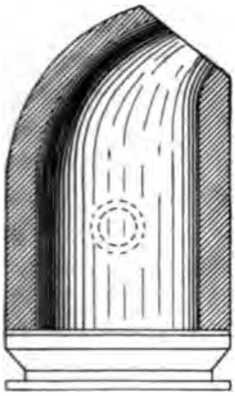


Fig. 6.

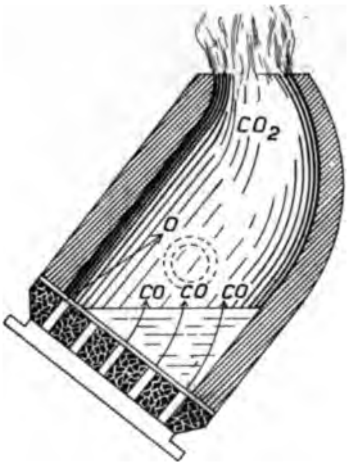


Fig. 7.

In case there is too much silicon for good working, or if the charge is too hot, cold steel scrap is dropped into the nose of the converter from a platform above. The scrap, being free from silicon, reduces the percentage of silicon in the converter. If the steel is made too hot it will not roll well. Sometimes a jet of steam is admitted to the blast pipe to cool down a charge. The carbon is reduced to about .05 per cent after about 12 minutes blowing under a pressure of 30 pounds per square inch. This is shown by a shorter flame. An instant later the flame becomes fringed with brown smoke which is Fe_2O_3. The converter is now ready for the spiegel. The spiegel contains about 20 per cent manganese and 4.5 per cent carbon. If hard steel is being made, spiegel is used, but if it is to be soft, which requires some manganese and but little carbon, ferro-manganese is used instead of spiegel. This has 80 per cent manganese and 6.5 per cent carbon. The amount of molten spiegel added is about 10 per cent of the weight of the converter charge, and of ferro-manganese from 1 per cent to .8 per cent. The ferro-manganese is not remelted but shoveled red hot in pieces the size of an egg into the casting ladle. After the steel has been poured out into the ladle most of the slag remains in the converter. It is dumped into a car beneath by tipping the converter bottom up. This loss or waste is from 10 per cent to 12 per cent.

The charge varies from 5 tons in a small converter to 20 tons in a large one, and a new charge is blown every twenty minutes. The bottoms of the converters are examined and any bad tuyeres are plugged with plumbago mud and blanked. The life of one of these bottoms varies from 18 to 25 "blows." The conditions which injure the bottom are low blast, a great depth of metal above the tuyeres, too much Al_2O_3 and Fe_2O_3 in the ganister mixture, and dampness of the repairing material. The bottoms are dried four days in a drying oven; several of these are always kept on hand drying, for if not absolutely dry, they are useless.

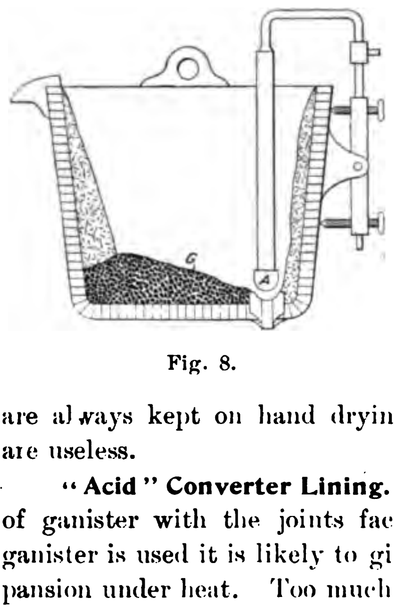


Fig. 8.

"Acid" Converter Lining. Converters are lined with blocks of ganister with the joints faced with ganister mud. If pure ganister is used it is likely to give trouble on account of its expansion under heat. Too much Al_2O_3 causes the lining to melt out rapidly. The bottom is lined with a mixture of ground ganister and fire clay. Ganister, a flinty sandstone, is composed of about 98 per cent of SiO_2 with about 1 per cent or 2 per cent of $Fe_2O_3 + Al_2O_3$. The fire clay has about 86 per cent of SiO_2, 10 per cent Al_2O_3 and 4 per cent of alkalies. If the manganese in the pig iron is less than 1½ per cent the linings last for months. A high lime slag in the pig will rapidly flux the SiO_2 of the lining. The nose section is lined with brick or stone and lasts but a short time.

The Casting Ladle. The general shape and arrangement of the casting ladle is shown in Fig. 8. The shell is made of iron plate and is lined with a layer of brick and upon this is pounded moist loam. The bottom G is made of rammed ganister material. The pouring hole is fitted with a cylindrical brick nozzle, with a hole 2 to 4 inches in diameter. The stopper A sets upon a bowl shaped seat. The stopper and stopper slide are shown in the figure. The end of this stopper, which fits the seat. is made of plumbago. The lining of the casting ladle lasts about 40 blows. A new nozzle and stopper is put in about every fourth blow.

Moulds. The moulds must be hard enough to withstand the strain caused by expansion and contraction when heated or cooled, yet not brittle. These moulds, if made of iron have a composition as follows:

Silicon	1.7 per cent
Phosphorus	.1 per cent
Manganese	.75 per cent

Moulds are made of gray iron as white iron is too brittle These moulds last about 90 operations.

INGOTS.

Method of Pouring. Great care is necessary in the pouring of ingots. They should be poured in such a manner as to prevent spattering, oxidation of the surface and injury to the mould. There are three principal methods: Top pouring, the most natural, bottom pouring, and a combination of top and bottom pouring. The greatest objection to ordinary top pouring is that of spattering and oxidation of the surface. These are partly overcome by the admission of the molten metal through a pipe which reaches nearly to the bottom of the mould. By mechanical means, this pipe slowly recedes, so that the distance between its end and the surface of the metal is nearly constant. If the mould is bottom poured, the metal at the bottom, being kept hot, has a tendency to thin the bottom and walls of the mould. If they become too thin they are likely to crack or burst. The slag has to rise through the entire column of metal and if this becomes cooled particles of slag become entangled. Also, the slag has a tendency to solidify in the pipe by which the metal is introduced, thus causing poor ingots. The best results have been obtained from a combination of top and bottom pouring. During the first half of the time the metal is bottom poured and then finished by top pouring. In this case, the gases and slag have only a short distance to rise.

Shape of Ingots. Ingots are usually square with rounded corners slightly tapered to one end, so that they may be easily removed from the mould.

Gases and slag rise to the top of the ingot. Sometimes a "pipe" is formed in the center by the metal solidifying and shrinking away from the center. To prevent this the top is kept liquid longer by a covering of sand. It is advantageous to keep the cavity near the top, so that a large portion of the ingot will be sound. Another method is to cast ingots one on top of the other in a column, pouring one as soon as the preceding one has begun to solidify. This brings the cavity and imperfections in the last ingot. Another remedy is to cast the ingots longer than is necessary and cut off the top; but this is a waste of metal for the cut off portion has to be remelted and recast. Another way is to make the top rounding, in order to allow the impurities and gases to collect in the rounded part.

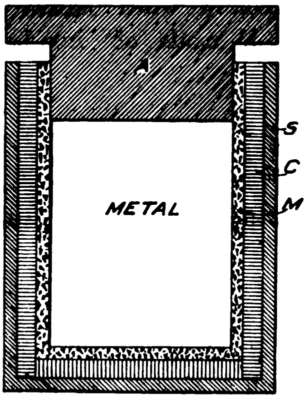


Fig. 9.

We learn from Chemistry that the solubility of gases in liquids increases with pressure; this principle is made use of in the casting of ingots. The mould is arranged as in the accompanying diagram, Fig. 9. The outside S is formed of steel in which is a thin layer C of perforated cast iron, the mould being lined with moulding sand M. The top plunger A is stationary The mould is made to rise by powerful machinery. When the metal has begun to solidify the mould is raised until the pressure becomes 10 to 20 tons per square inch; this pressure is kept on for about 20 minutes. The gases are not squeezed out by this process; the pressure tends to dissolve them. This process is used in making armour plate and gun tubes, but is too expensive for ordinary use.

Rail Making. Very soon after an ingot is poured it commences to solidify at the surface. A solid shell forms with a pasty or liquid interior. As the ingot cannot be rolled until it has become of uniform softness it is put in a "soaking pit." By means of currents of hot gases, the ingot soaks or equalizes, that is, it becomes uniform throughout. It soaks in these hot gases for about an hour. The ingot is taken from the soaking pit by an electric traveller, and is rolled down in the blooming mill to a "bloom" of about 7 inches by 7 inches in section, which, after the ragged edges have been cut off by hydraulic or steam shears, is finished, without re-heating, in a rail mill. Sometimes the bloom is allowed to partially cool and is then reheated before being finished. This process is expensive on account of the fuel and labor, but it reduces the number of defective rails. The whole ingot is rolled in the rail mill into one long rail, and this is cut into standard lengths by hot saws. After the rails cool they are straightened in steam presses and are then inspected and bolt holes drilled in the ends. Steel rails have the following composition:

Carbon,	.40 per cent to .6 per cent
Phosphorus,	.08 per cent to .1 per cent
Manganese,	.75 per cent to .9 per cent
Sulphur,	.05 per cent to .1 per cent
Silicon,	.05 per cent to .15 per cent
and sometimes Copper,	.01 per cent to .2 per cent

If the carbon is above .6 per cent the rail will be too brittle and will break under the drop test. In this test a heavy weight is allowed to fall through a specified distance on a piece of rail about 3 feet long, supported at the ends.

If the carbon is below .4 per cent the rail is too soft to stand the wear of the car wheels; if the phosphorous is above .1 per cent the steel will be "cold short" (brittle); if the manganese is much below .75 per cent the ingot will crack in rolling; if the sulphur is above .1 per cent there will be short feathery cracks in the ingot when rolled, especially if rolled at a low red heat. Silicon up to .15 per cent improves the rolling qualities of the steel, but makes the steel brittle if the percentage of silicon is much higher.

The Bessemer process is also used in making soft steel. This steel is made into barbed wire, wire nails, hoop iron and sheets for tin plate and galvanized iron; it is also used for some structural steels and agricultural implements. This steel has about .1 per cent to .15 per cent carbon, and .4 per cent to .5 per cent manganese.

About 70 per cent of the steel made in the United States is Bessemer steel, and about 30 per cent of this is made into rails.

THE OPEN HEARTH PROCESS.

The Open Hearth Process for making steel is divided into three methods, according to the character of the material used. They are,

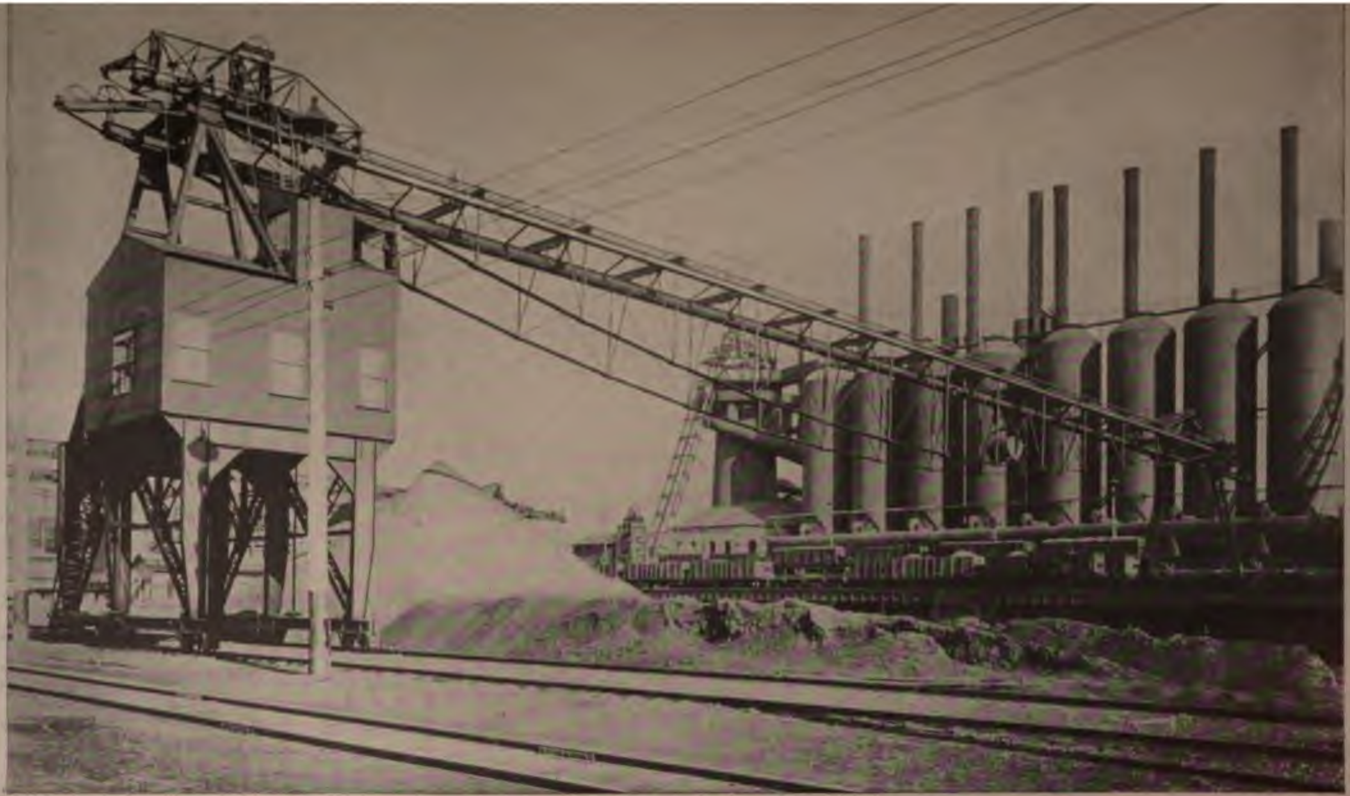
1, The Martin Process, in which pig iron and scrap are used.

2, The Siemens Process, or "pig and ore" in which pig iron and ore are used.

3, The Combination Process, using pig iron, scrap and iron ore.

The open hearth process was made possible by the invention by Siemens of the regenerative chambers, first successfully used by Martin, and is often called the Siemens and Martin process. The fuel is gas, which is burned on the hearth of a large reverberatory furnace. Both the gas and air are heated by the products of combustion in the regenerative chambers, as represented by Fig. 10. The heated gas and air enter the furnace on the left, burn on hearth H, and the products of combustion pass out and down through the chambers A and G on the right. These chambers are filled with fire brick set up with spaces between, called checker work, which becomes heated to a white heat. After a time the currents of gas and air are reversed and pass through the checker work just heated, becoming highly heated before they combine and burn, thus the heat is "regenerated."

The currents are reversed once every half-hour (to an hour)



ORE-STORAGE AND REHANDLING PLANT.
Duquesne Furnaces, Carnegie Steel Co., Limited.

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and a very intense heat is maintained so that the metal in the condition of wrought iron is kept in a molten state.

In this country the combination process is generally used. With this process the scrap and pig iron are first melted. As this iron contains too much carbon, iron ore is added to reduce the percentage. This process, like the Bessemer, has two main divisions, the Acid and the Basic open-hearth processes, having siliceous and lime-magnesia linings respectively, and like the Bessemer process, only low phosphorous iron can be used with the acid lining while high phosphorous stock is used with the lime lining. In the Bessemer process only medium and low carbon steels can be made, while in the open-hearth, steel of any grade of carbon can be made. This process also has the advantage of being more under control, and the product is more uniform, more reliable and contains less gas. Open-hearth steel costs about $2.00 a ton more than Bessemer.

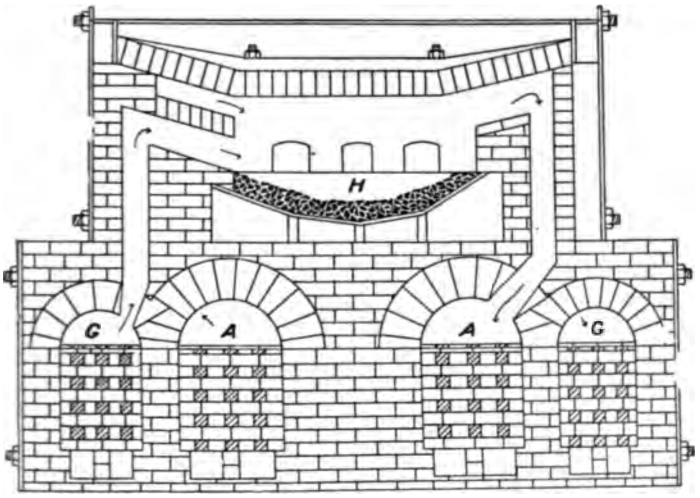


Fig. 10.

Open-hearth steel is used for making spring steel (carbon .8 per cent to 1 per cent) for cars and wagons; structural steel for bridges and buildings; steel for agricultural implements and tools; cast steel and mild steel (low carbon) for boiler plates (carbon .15 per cent, and phosphorus .03 per cent).

The Bessemer process and open-hearth process can be advantageously carried on together, as the scrap and "crop ends" of the Bessemer are largely used in the open-hearth.

MANAGEMENT, OR RUNNING THE ACID PROCESS.

At the start the furnace is heated by a wood fire, and then the gas is turned on and lighted. When the temperature is sufficiently high to melt steel, the charge is put in. It consists of one-third pig iron, and the rest wrought iron and steel scrap. On account of the low melting point of pig iron, one-half of the pig iron is put in first on the bottom. If steel or wrought iron were charged first, it would be slow in melting. The scrap is then put on and covered by the rest of the pig, and currents of air and gas are reversed at intervals, each time coming up hotter. In four hours it is all melted, but the carbon is too high, and it is not yet ready for casting. To expel this carbon small amounts of iron ore are added. CO is produced, which boils off.

$$Fe_2O_3 + 3C = 3CO + 2Fe.$$

This boiling continues until the desired percentage of carbon is reached, which is determined by sampling. These samples are taken out at intervals, cooled and broken ; the percentage of carbon being judged by the appearance of the fracture. As the boiling down occupies three or four hours, there is time for an approximate chemical analysis. Manganese and silicon have both been absorbed by the slag, therefore some manganese must be added before casting. This is done by adding to the casting-ladle red-hot spiegel, or ferro-manganese, the size of peas. If steel castings are being made, a little silicon must also be added, to prevent blow-holes. When the steel is ready chemically, it is usually hot enough to cast. The furnace is tapped by driving a bar through the tap-hole, and the molten metal flows out of it into the casting-ladle, which is similar to that of the Bessemer process. The casting is done in moulds, as in the Bessemer process. Bottom pouring is often employed, especially if the ingot is to be made into steel plate. The bottom of the mould has to be repaired after each operation.

MANAGEMENT OR RUNNING THE BASIC PROCESS.

The furnace used is very similar to that of the acid process, except for the lining, which is of dolomite or magnesite. Dolomite is hard-burned lime made from a magnesia limestone. Magnesite is made from $MgCO_3$, calcined several times at high heat. Layers of dolomite or magnesite, mixed with 10 per cent of boiled tar, is rammed in with hot rammers all over the bottom and sides, above the slag line. Upon this hearth, scrap and high phosphorous pig iron are melted down. To prevent fluxing of the lime lining, limestone is spread over the bottom before charging. After melting there is too much phosphorus and carbon in the charge. These elements are oxidized by the addition of the iron ore. The agitation and boiling of the phosphoric bath is caused by the escaping gas, CO, and the metal is thus brought in contact with the basic slag and the phosphorus removed. If all the phosphorus is not out at this point, pig iron is added to raise the percentage of the carbon, and the bath is again boiled down. The appearance of the fracture of the sample indicates the amount of phosphorus present. If there is a large amount, two cross-lines of bright crystals, called the "Phosphorus Cross," appear in the center. The casting is the same as in the Bessemer process. The wear of the basic lining is greater than that of the acid, especially if the silicon is high. Holes in the hearth are repaired after each heat.

The tap-hole is rammed with tar dolomite or magnesite.

In an ordinary open-hearth furnace only two heats can be made in a day. The charge varies from 10 tons in a small furnace to 50 tons in a large one.

Tilting furnaces are being used in modern plants, which lessen the time of charging and working, and "direct metal" from mixers is used in place of pig, which further reduces the time. Altogether, the open-hearth process is gaining in favor in this country. The basic process is more used than the acid, because high phosphorous pig is cheaper.

GAS PRODUCERS.

Gas is the fuel used in the open-hearth process. The Siemens Gas Producer is now little used, most gas being made by the

Wellman Gas Producer. Fig. 11 is the sectional view of this producer. A forced draft, usually a steam-jet injector, supplies steam and air to the furnace under slight pressure. The following reactions take place when air or steam unite with coal:

$$\begin{aligned} C + O_2 &= CO_2 \\ CO_2 + C &= 2\,CO \\ H_2O + C &= CO + 2\,H \end{aligned}$$

The resulting producer gas has about the following composition:

Nitrogen,	60.3 per cent
Carbon Monoxide,	22.8 per cent
Carbon Dioxide,	5.2 per cent
Oxygen,	0.4 per cent
Hydrogen,	8.5 per cent
Hydrocarbons,	2.8 per cent

In running the producer, there is a heat loss of about 35 per cent, principally in radiation, ashes, latent heat, decomposition of steam, and sensible heat of gas. Another producer, the Taylor Producer, has in place of the grate-bars a revolving dome-shaped plate, through which air is driven into the center of the fire. In place of the brick lining this producer has a water-jacket. Bituminous coal is the fuel generally used in these producers. As this gas contains about 60 per cent nitrogen, it is weak fuel. In a few localities natural gas, a stronger fuel, is obtained. A gas made of vaporized petroleum mixed with dry steam and forced through a red-hot metallic retort, is used in the Archer process.

SPECIAL STEELS.

Nickel Steel. Nickel steel is made by adding metallic nickel, nickel ore, or ferro-nickel, to the bath of the open-hearth process. The nickel increases its density, elasticity and strength. This steel is used for armour plate, on account of these qualities, and also because it does not corrode. Nickel steel contains about 4 per cent nickel, .3 per cent carbon, .7 per cent manganese, and .02 per cent phosphorus. For such uses as bicycle tubes, shafts, axles, etc., the high elastic limit of nickel steel tends to prolong indefinitely the life of the piece, and because of its superior toughness, offers greater resistance to sudden strains and shocks.

Aluminum Steel. From .05 per cent to .1 per cent aluminum in steel castings reduces the melting point, prevents blowholes, and keeps the metal liquid while being poured. Aluminum gives no increase of hardness.

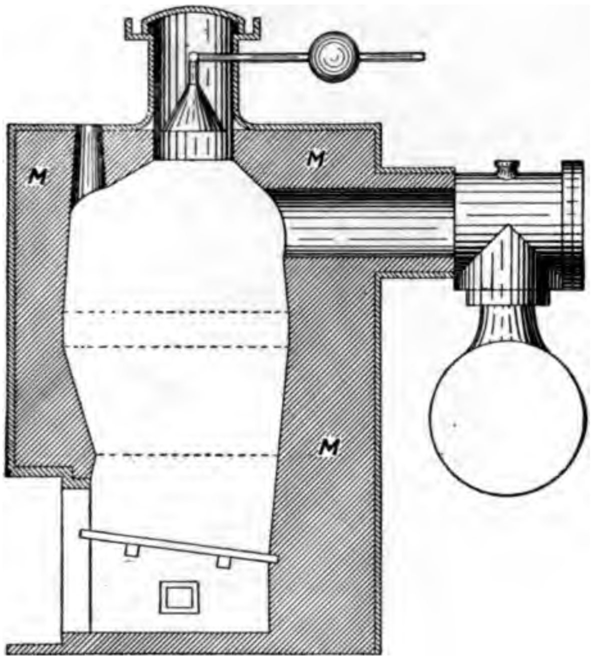


Fig. 11.

Chrome Steel. If chromite is melted in brasque crucibles with charcoal, the result, ferro-chrome, which has 40 per cent chrome and 48 per cent iron, is used in making chrome steel, by melting it with bar iron in crucibles. Chrome, like manganese, hardens iron. It also makes it more forgeable. It is used, on account of its hardness, for burglar-proof safes, but it is not entirely satisfactory, and other steels are fast driving it out. It has about the following composition: chromium, .5 per cent to 3 per cent; carbon, .5 per cent to .9 per cent.

Manganese Steel. Manganese steel is an alloy of iron and manganese, containing a considerable proportion of carbon. It there is a very small portion of manganese, the effect is slight. As the proportion of manganese rises above 2.5 per cent the strength and ductility diminish, while the hardness increases. This hardening effect is a maximum with about 6 per cent manganese. Above this the strength and ductility both increase, and at 14 per cent of manganese the metal is so hard that it is difficult to cut with steel tools. It welds with great difficulty, but it can be forged. Its toughness increases by quenching from a yellow heat. It has a remarkable combination of great hardness, which cannot be lessened by annealing, great tensile strength, toughness and ductility. The fact that it cannot be machined, on account of its hardness, limits its usefulness. It is used principally for car-wheels, dies and crusher-jaws.

Tungsten Steel. Steel containing a little carbon and tungsten is much harder than steel with carbon alone, and yet not very brittle. A specimen from Sheffield, England, for chisels, used untempered to turn chilled rolls, was not brittle, yet it was hard enough to scratch glass. It contained 9.3 per cent tungsten, .7 per cent silver and .6 per cent carbon. In working this metal it has to be given its final shape by hammering at red heat, and if the percentage of tungsten is high it is necessary to reheat it while it is being hammered. After the desired shape is reached the hammering must be continued, with numerous blows, until it becomes nearly cold. Tungsten is employed to produce steel of moderate hardness, with great toughness, resistance and ductility. Its principal use is for cutting-tools. It is self-hardening.

CASE-HARDENING.

By the process called case-hardening, a thin layer of steel is formed over the iron. To do this, iron is heated to redness, and powdered potassic ferro-cyanide. $K_4Fe(CN)_6$, is sprinkled over the surface. When suddenly cooled, the surface of the iron is hard enough to resist a file. The chemical reaction which takes place is

$$K_4Fe(CN)_6 = 4KCN + FeC_2 + N_2.$$

THE HARVEY PROCESS.

The Harvey process for making armor plate is somewhat like case-hardening. The outside of the heated steel plate is covered with charcoal, from which it absorbs carbon in the same manner as wrought iron absorbs carbon in making cement steel. The layer of hard steel thus formed is further hardened by quenching with water. This makes a plate with an exceedingly hard surface, which breaks up shot and shell. The backing is, however, tough, mild steel.

THE EFFECTS OF THE ELEMENTS IN STEEL.

The following from Howes' Metallurgy of Steel will give an idea of the effects of the elements:

Carbon. Carbon up to 1.5 per cent increases Tensile Strength, Compressive Strength, and raises the Elastic Limit; decreases the malleability and welding power.

Silicon. Silicon increases hardness, Tensile Strength and solidity, and prevents blow-holes. Too much silicon makes steel brittle. From .3 per cent to .5 per cent should be the maximum.

Sulphur. Sulphur causes hot shortness; that is, the metal is brittle when hot, both under the hammer and rolls.

Arsenic has the same effects as sulphur.

Phosphorus causes cold shortness. It makes steel hard and liable to break. It increases the Elastic Limit and reduces Elongation.

Manganese prevents hot shortness and blow-holes, removes or offsets the effect of sulphur. It increases Toughness, Elongation and Tensile Strength. Too much manganese makes steel brittle when cold, especially after quenching.

Copper. Copper causes red shortness; .5 per cent may be allowed in rails, but 2 per cent makes steel worthless. Tin steels are not forgeable or ductile, either hot or cold.

TEMPERING.

Tempering steel is the process of giving it, after it has been shaped, the necessary hardness to do its work. A piece of steel after it has been properly tempered should be finer in grain than the bar from which it was made.

This is accomplished by first hardening the piece, usually harder than necessary, and then toughening it by slowly heating and gradually softening, until it is just right for the work. The process is as follows: The tool to be tempered is heated to a cherry red, and plunged into cold water or oil to a depth somewhat above the cutting edge. When this portion has become entirely cold, the piece is taken out and the cold end polished, usually with emery-cloth; the point is now too hard and brittle. The heat contained in the hot portion gradually enters by conductivity into the quenched part, and as it does so, colors are formed which denote temperature. The colors seen in order are pale yellow, straw, brownish yellow, light purple, dark purple, blue. They are formed by oxide on the surface. These colors run from the hot portion to the cutting edge, and when the proper color reaches the cutting edge, the whole piece is quenched. Some tools are of such a shape that the temper must be "drawn" to the desired color by reheating the piece between hot plates or in a hot iron ring.

The following list will give some idea of the colors, temperature and hardness of tools:

Very pale Yellow, temperature about 430° F.	Steel-engraving Tools. Turning Tools. Hammer Faces. Planer Tools. Wood-engraving Tools.
Straw Yellow, temperature about 460° F.	Dies. Taps. Drills. Punches. Reamers.
Brown Yellow, temperature about 500° F.	Gouges. Plane Irons. Twist Drills. Cooper Tools. Wood-boring Cutters.
Light Purple, temperature about 530° F.	Augers. Surgical Instruments. Cold Chisels. Edging Cutters.
Dark Purple, temperature about 550° F.	Axes. Gimlets. Needles. Hack Saws. Screwdrivers. Springs. Wood Saws.

COPPER.

As copper occurs in the metallic state, it was one of the earliest known metals. The native copper deposits of the Lake Superior region were worked by prehistoric inhabitants. Copper compounded with tin was the metal of the Bronze Age. With the exception of iron, copper is our most useful and important metal.

ORES.

The native copper of Lake Superior is still an important source of supply, but by far the largest quantity is obtained from the sulphide ores, of which Copper Pyrites (Cu_2 S. Fe_2 S_3) is the most important. When pure it contains 34.6 per cent of copper, 30.57 per cent iron and 34.9 per cent sulphur, but the average ore carries only about 12 per cent of copper. Spanish iron pyrites is another source of supply; it is first used in the manufacture of sulphuric acid, after which the copper is extracted from the "cinder." It contains only 3 or 4 per cent of copper, but carries also a small proportion of gold and silver, which makes it a profitable ore.

Carbonate ores, formed by the weathering of the sulphides are now about exhausted, as they occur only a short distance below the surface.

EXTRACTION.

There are two main processes for extracting copper from its ores:

(1) Process involving fusion.

(2) Wet process used for low-grade ores.

The most important fusion method is the "Welch" or "Reaction" process. The prepared sulphide ore is first roasted in heaps, kilns or a reverberatory furnace. Care is taken that not too much of the sulphur is expelled. Next, this calcined ore is fused in a reverberatory furnace. The copper has a greater affinity for the remaining sulphur than any of the other metals, and copper sulphide is formed.

$$Cu_2O + FeS = Cu_2S + FeO.$$

The ferrous oxide (FeO) and the silica unite and form a slag, which carries away lime or other impurities present. The cuprous sulphide Cu_2S combines with the excess of iron sulphide left in the charge, forming a fusible substance called a "regulus," or first copper matte, which contains about 30 per cent of copper. This first matte is again roasted and fused, and part of the iron slagged away as before, leaving the second matte, which contains about 50 per cent, if "blue metal" is wanted, or 75 per cent of copper, if "white metal" is being made. A small amount of metallic copper is also produced. These copper bottoms contain most of the impurities, including much of the gold and silver.

In a third reverberatory furnace the second matte is again partly oxidized and then fused, the product this time being crude metallic copper and a slag rich in copper. The rich slags from the first and second matte are worked up for their copper. The reactions by which metallic copper is produced are:

(1) $2Cu_2O + Cu_2S = 6Cu + SO_2$

(2) $3Cu_2O + FeS = 6Cu + FeO + SO_2$

The SO_2 gas passes away and the FeO goes into the slag.

Producer gas is used for heating the furnaces in modern plants.

CUPOLA SMELTING.

In the first stages of this process the chemical action is about the same as the "Welch" method. A first and second "Matte" is produced in small water-jacketed blast furnaces of rectangular sections using cold blast. (See Fig. 12.) Some "black copper" is produced with the second matte.

The second matte, called "white metal," is now completely roasted to oxide. This oxide of copper is reduced to metallic copper in a blast furnace by CO gas in the same manner as in the production of iron.

The reaction is

$$Cu_2O + CO = 2Cu + CO_2$$

The fuel is coke or charcoal. The slag from the first matte is thrown away, but the other slags go back into the process.

Less skilled labor is necessary in the cupola method and less fuel is required. It is consequently in favor in remote regions. The metal of oxidized ores (carbonates) can be extracted by this process in one operation. The reverberatory method produces purer copper, and must be used when there is much antimony and arsenic in the ore. Highly refractory ores, which are difficult to fuse in a blast furnace, can be better treated in reverberatories, as the slag can be skimmed off in a partly melted condition.

The variations in the foregoing processes are numerous. A common American practice is to use the cupola for obtaining the first matte, and finish the process in reverberatory furnaces.

Modified Bessemer converters are now successfully used to convert copper matte into crude copper. The converter has the tuyeres in the sides, and is lined with silica and clay. As the wear on the lining is very great, provision is made for quickly replacing a worn-out converter by one which has been relined. Mattes containing from 30 to 60 per cent copper have been thus successfully treated at a considerable saving of expense.

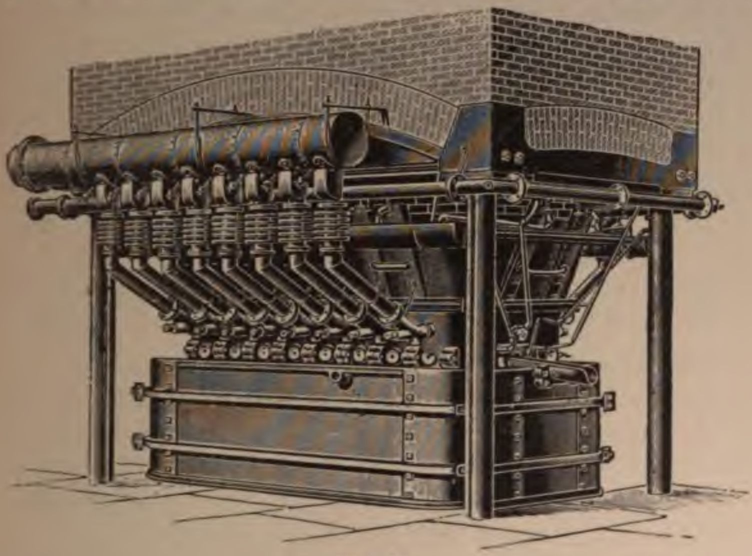


Fig. 12.

REFINING.

The crude copper produced by any of the foregoing methods is refined in a reverberatory furnace with a large hearth. It is slowly melted down with an excess of air. The impurities oxidize first and form a slag with the silica from the lining of the furnace. This slag is frequently skimmed off. The copper finally begins to oxidize, forming Cu_2O, which acts on any Cu_2S, forming SO_2, which causes the molten metal to boil. When this action ceases, the copper contains too much copper oxide. This is reduced by "poling." Poles of green wood are thrust into the bath, and the distilled hydrocarbon gases cause the bath to boil, which expels any SO_2 gas remaining. Charcoal is spread over the molten metal, which, with the hydrocarbon gas, removes the oxygen from the Cu_2O, leaving metallic copper. Samples are taken out from time to time, and when the color changes from red to flesh color, and the sample becomes fibrous with silky lustre and can be bent double, the refining is finished. The rich slags go back into the process. A little oxide of copper is left in the metal, as it neutralizes the effect of the small amount of remaining impurities.

The metal is then run into small moulds. An ingot "under poled," containing too much oxide, will show a furrow along its surface. An ingot with the right proportion will have a flat surface, called "tough pitch," and one which is "over poled," containing too little oxide, will show a ridge.

Electric refining is fast replacing this older method. In the United States two-thirds of the product is thus refined. By the electrical method all the gold and silver in the copper is recovered, and the copper produced is very pure. The crude copper is cast into slabs as it runs from the furnace. A row of slabs is placed in a tank containing a solution of copper sulphate made acid with sulphuric acid. These form the dissolving plates, and opposite each is placed a thin sheet of pure copper. The tanks are connected in series by wires and the current passed through. The electric current causes the crude copper to dissolve and pure copper to be deposited on the thin plates. The gold and silver, together with other impurities, fall to the bottom as mud or "slimes," from which the precious metals are extracted by chemical processes.

The *wet process* is used for lean ores. It has the advantage of extracting at the same time any gold and silver present. This process involves getting the copper and precious metals into solution either as sulphate or chloride and then the copper is precipitated by electrolysis, metallic iron or quicklime.

The solutions are produced either by dissolving in the dilute acids or roasting the sulphide to sulphate or by roasting with salt to obtain the chloride and then leaching with water.

PROPERTIES OF COPPER.

Copper is a rather soft metal and is very ductile and malleable. It can be worked both hot and cold, but should not be heated too hot, as it crystallizes and takes up oxygen. When worked cold it is stronger and harder, but less ductile. Heating and quenching make it softer. Rolled sheet copper has a tensile strength of from 24,000 to 28,000 pounds per square inch, and annealed wire over 40,000 pounds per square inch. Good castings cannot be made from pure copper because they contain blowholes and the shrinkage is too great.

Copper is not affected by the weather, but in damp places it is slowly corroded; carbonate of copper, called verdigris, being formed by the carbonic acid of the air.

The thermal conductivity of copper is high.

The electrical conductivity of good copper is but little less than that of silver, and is about six times that of iron. A very small amount of impurity reduces its electrical conductivity as much as 10 per cent. Antimony is the most harmful impurity from a mechanical standpoint, and should not be over .02 per cent.

The growth of electrical industries has greatly increased the demand and price of copper of late years. It is estimated that 60 per cent of the world's production of copper is consumed in electrical work. The United States produces over 55 per cent of the world's output of copper, or over a quarter of a million long tons annually.

LEAD.

The most important ore of lead is Galena, lead sulphide (PbS). In the United States it is found in the upper valleys of the Mississippi and Missouri Rivers and in the Rocky Mountains. The mines of Spain, Germany and England furnish the bulk of the European product. It occurs in bright, shining, cubic crystals of metallic lustre. When pure it contains 86.6 per cent of lead. Galena usually contains silver, and frequently a small amount of gold. It is associated with sulphides of zinc, antimony, copper and iron. As it is a very heavy mineral it is easily concentrated.

Cerussite — lead carbonate, $PbCO_3$, — is an ore of some importance and is mined in Leadville, Colorado.

SMELTING.

Lead ore is smelted either in reverberatory furnaces or blast furnaces. When using the reverberatory furnace with sulphide ore, the chemical action whereby lead is produced is much the same as in the final stage of copper smelting in the "Welch" method. The ore is partially oxidized to lead oxide, PbO, at a low heat, some sulphate, $PbSO_4$, also being formed. Then the temperature is raised and the lead is produced according to the following reactions:

(1) $PbS + 2PbO = 3Pb + SO_2$

(2) $PbS + PbSO_4 = 2Pb + 2SO_2$

The lead as it is formed runs into a pot, and the operation is repeated until no more lead can be extracted, when it is tapped and the slag withdrawn in a pasty condition. This "gray slag" is usually smelted in a blast furnace for the lead it still contains. This method is simple and the apparatus inexpensive, but its use is limited to high-grade ores containing 60 per cent to 70 per cent of lead, and only 4 or 5 per cent silica. The process requires much fuel and skilled labor.

SMELTING IN A CUPOLA OR BLAST FURNACE.

This process is used for all ores containing over 4 per cent silica, for carbonate ores, and for various lead slags and drosses obtained in purifying the crude lead.

The Furnace is built of brick and lined with fire brick. It is usually oblong in section. The shaft is from 14 to 20 feet high and tapers downward to the boshes, which taper more sharply to the crucible. The section at the crucible is usually about 12 feet by 3 feet 6 inches. The tuyeres, 6 or 8 in number, are placed on each side, near the top of the crucible. The boshes and part of the crucible are cooled by cast or wrought iron water jackets. The furnace is charged through a door in the side, near the top.

As lead is somewhat volatile, provision must always be made for collecting the lead fumes. Various devices have been tried, but long flues, wherein the fumes condense and settle, are most commonly used. The top of the furnace is connected with one of these flues.

The sulphide ores are roasted in a reverberatory furnace or in hand or mechanical kilns. The roasted ore is charged into the blast furnace with suitable fluxes and various mixtures of coke, charcoal and coal as fuel. Iron plays an important part in the smelting, as it is capable of decomposing silicate of lead and is added as an iron slag or as ore if not present in correct amount.

In smelting there is usually a small amount of matte formed, consisting of sulphides of iron, copper, nickel and lead. This is tapped with the slag into a slag pot, where it rises to the top and is separated when the mass cools. The matte is broken up and roasted and its lead and copper recovered. The lead collects in the crucible and is tapped out at intervals.

SOFTENING AND DESILVERIZING.

The lead obtained by either the reverberatory or blast furnace method contains copper, arsenic, antimony and other metals in addition to silver. The impure lead is slowly melted down in a reverberatory furnace. The lead, having a lower melting point than the impurities, liquefies first, leaving a residue containing the copper and part of the arsenic and antimony. The lead is next heated very hot with an excess of air, and then most of the remaining impurities oxidize and form a scum, which is skimmed off. The silver remains with the softened lead and is extracted by the Park's Process. This process depends upon the fact that a small percentage of zinc added to the molten lead will collect all the gold and silver to form an alloy, which, being of less specific gravity, rises to the top, and having a higher melting point solidifies before the lead.

From the softening furnace the molten lead is run directly into a large kettle. Here from 1 to 3 per cent of zinc is added to three successive portions. After each addition the mass is well stirred and then allowed to cool somewhat, when a crust is formed, which is removed. The first crust contains most of the gold and is called the gold crust. The second crust is called the silver crust, and the third crust, containing the silver that still remains, is used for the first addition to the next charge.

RECOVERY OF THE SILVER AND GOLD.

The gold and silver crusts are melted slowly in a kettle or reverberatory furnace, and most of the lead mixed with the crust melts out and is recovered. The zinc is distilled off in large graphite retorts, leaving a small amount of lead, which contains all of the silver and gold. The lead is separated from the precious metals by cupelling. In the cupelling furnace the lead is oxidized to litharge (PbO), leaving the metallic silver and gold. The furnace has a hearth made of porous material, which absorbs part of the melted litharge as it forms; the remainder runs into a pot. The litharge is ground and sold if it does not contain too much silver, in which case it is smelted again. About 60 per cent of zinc is recovered in metallic form and is used again in the desilverizing kettle.

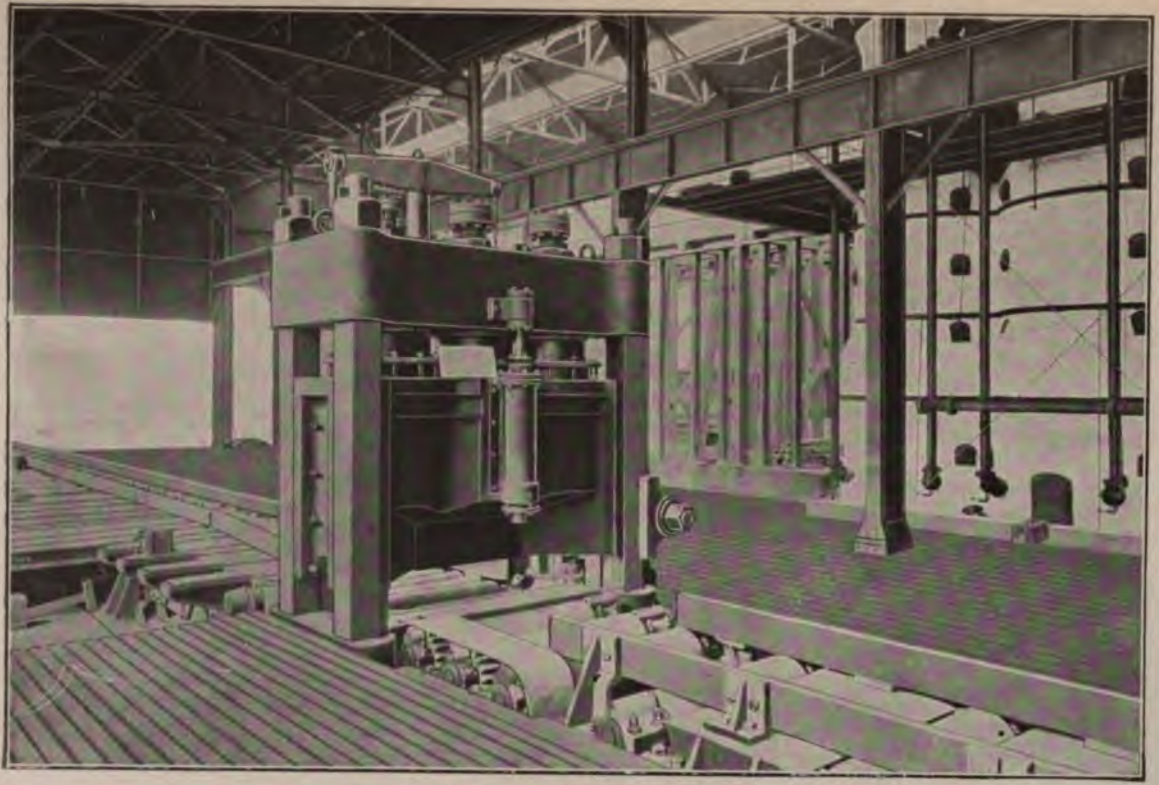
REFINING THE DESILVERIZED LEAD.

The desilverized lead contains .6 per cent to .7 per cent of zinc, which is removed in a reverberatory furnace or large kettle. The charge is heated very hot in the reverberatory, and the zinc in part volatilizes; then the doors are opened and the remainder of the zinc is oxidized, and with some lead oxide is skimmed off. This is repeated until the zinc is entirely removed.

When refined in a kettle, steam is forced into the molten charge; the zinc and a little lead oxidize and form a scum, which is skimmed off.

The desilverized and refined lead is run into iron molds on wheels, and when cooled is ready for the market. The amount of marketable lead obtained is about 80 per cent of the impure lead. By using the Howard "stirrer," "skimmer" and "press" for the gold and silver crusts, 85 per cent has been obtained and 70 per cent of the zinc recovered.

An older process for desilverizing lead is the Paterson Process. It is found that when molten lead is cooled slowly, crystals of lead form which contain less silver and other impurities than the remaining molten mass. By repeated crystallization the silver is concentrated in a portion of the lead, and the remainder is almost free from silver. The silver-bearing portion, which must be cupelled, is about 30 per cent of the whole against 5 per cent in



HYDRAULIC BLOOM SHEAR.

The Wellman-Seaver-Morgan Co.

the Park's Process. The Paterson Process is not used in the United States.

The working up and recovery of all the by-products formed in the smelting of lead is a very important and very complex part of the process.

PROPERTIES OF LEAD.

Lead is the softest and heaviest common metal. It is very malleable and ductile, but has little tenacity. Lead is insoluble in sulphuric acid of moderate strength and is not much affected by cold hydrochloric acid. It is used in chemical works in the manufacture of sulphuric acid and for other purposes. Ordinary water has little effect on lead. Pipes used for conveying water are soon covered with a thin layer of carbonate and sulphate of lead, which is insoluble and prevents further action.

Water from swamps, etc., however, dissolves small amounts of lead, which makes its use dangerous for domestic purposes. Water from new pipes or pipes which are not kept constantly full should not be used for household purposes, because of danger from poisoning.

Lead is not affected by dry air, but is slowly corroded in moist air.

TIN.

This metal was known to the ancients, and very successfully used by them for hardening copper. The most important ore is tin-stone, $Sn\,O_2$, and the principal mines are in Cornwall, England, and Banca in the East Indies.

The smelting is conducted in a reverberatory furnace. The concentrated ore, mixed with finely divided anthracite coal and with a little lime is heated on the bed of the furnace. The tin is produced and runs into the depressed center of the furnace, from which it is tapped and cast into pigs. This impure tin is refined by liquating and poling.

PROPERTIES AND USES.

Tin is white in color with a slightly yellowish shade. It has a peculiar odor, and when bent it gives out a crackling sound known as the "tin cry." It has little tenacity, considerable ductility, and is very malleable. It can be worked at about the boiling point of water, but becomes very brittle at 400° F. It can be rolled into very thin sheets; tinfoil being sometimes only one-thousandth of an inch thick. On account of its ductility it is readily made into tubes, wire, etc.

The bulk of this metal is used for tin plate. Thin sheets of mild steel are carefully cleaned and annealed and then dipped in a bath of molten tin covered with a layer of tallow. They are then passed through rolls to remove the superfluous tin, leaving a very thin coating of pure tin on both sides of each sheet. Tin plate finds numerous uses in the canning industries, for household utensils, etc.

Almost all of the remaining product is used for making alloys of tin, and only a comparatively small amount is used for pipes, sheets, etc., on account of the high price of this metal.

ZINC.

A large proportion of this metal is obtained from the ore called Zinc Blend, ZnS; the carbonate and silicate are also important ores, and considerable zinc is obtained from Franklinite.

In the metallurgy of zinc advantage is taken of the volatility of this metal. It can be distilled unchanged at 1040° F. The ore is roasted to oxide of zinc, ground and mixed with finely divided fuel and heated to a bright red in gas heated retorts. The carbon takes the oxygen from the zinc oxide, forming CO gas, and the zinc is set free and distills off. It is condensed in iron tubes which are kept at such a temperature that the zinc remains liquid and runs into a receiving vessel.

This zinc contains iron and other impurities, and is purified by redistillation. It comes on the market cast in slabs, and in this form is called "spelter."

PROPERTIES AND USES.

Zinc is a bluish white metal, brittle and crystalline. It is quite ductile at a temperature of 248° F., but is so brittle at 390° F. that it can be crushed to powder.

Zinc is readily dissolved by acids and alkalies, but is not affected by the weather. It is very largely used for galvanizing iron, which is done by dipping the carefully cleaned iron in a bath of molten zinc, using sal-ammoniac as a flux. Zinc protects the iron from oxidation, and is effective as long as any zinc remains on the iron, being the reverse of the action of tin plate which causes the iron to rust more quickly as soon as there is any flaw in the coating. Zinc is also used in making alloys and for batteries, sheets for roofing, etc.

ALUMINUM.

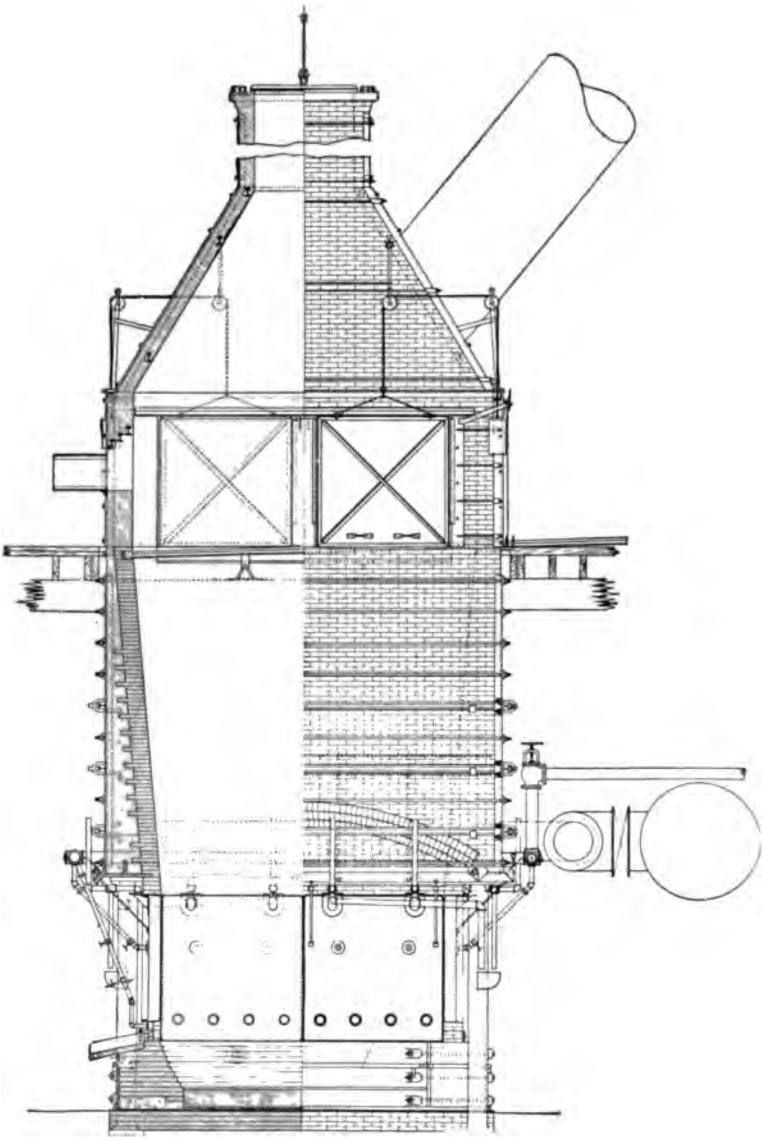
Aluminum has recently been transferred from a rare metal to one which, bulk for bulk is no more expensive than copper, by an electrolytic process invented by Hall. Beauxite, a hydrated oxide of aluminum is the important source of supply. Hall's process is conducted in a graphite lined vessel, and depends upon the property of cryolite — a double fluoride of sodium and aluminum, of dissolving fused oxide of aluminum. Cryolite melts at about 900° F. and then becomes a conductor of electricity. The bath is kept in a molten condition by a heavy current of electricity of low voltage. The oxide of alumina is sprinkled on the top of the bath and quickly dissolves, and is reduced by electrolysis to metallic aluminum which settles in the bottom of the crucible, from whence it is drawn from time to time.

If pure aluminum is desired the oxide of alumina used is obtained by a chemical process from beauxite.

PROPERTIES AND USES.

Aluminum is a grayish white metal, very malleable and ductile, and is a good conductor of both heat and electricity. It is acted on but feebly by sulphuric or nitric acid or by the organic acids. It is, however, dissolved by hydrochloric acid and the alkalies. Its most remarkable property is its extreme lightness, it being only about one-third as heavy as iron. It is fairly strong and imparts great tensile strength to its alloys. Good castings can be made from it, although the shrinkage on cooling is considerable. It can be worked cold, and is readily formed into sheets, wires, tubes, etc.

It is replacing copper to some extent as an electrical conductor, and is used for making a high class of kitchen utensils and a great variety of small ornamental articles. One objection to its use for some purposes is that it can be soldered only with difficulty.



SILVER-LEAD FURNACE.
Allis-Chalmers Co.

TABLE OF METALS.

NAME.	Specific Gravity.	Melting Point. Fahrenheit.	Electrical Conductivity. Silver = 100.	Heat Conductivity. Silver = 100.	Tensile Strength. lbs. per sq. in.	Weight per cu. in. in lbs.	Weight per cu. ft. in lbs.	Approximate Price per pound in Pigs, Billets, etc., 1902,
Cast iron	7.0 to 7.7	2100°	12.0	11.4	13,000 to 30,000	.260	445	¾¢
Wro't Iron	7.4 to 7.8	3000°	16.0	11.9	40,000 to 60,000	.278	485	1¾¢
Steel 0.1% C.	7.6 to 7.8	2500°	12.0	11.6	50,000 to 65,000	.283	490	1½¢
" 0.2% "					60,000 to 80,000			
" 0.4% "					70,000 to 100,000			
" 0.6% "					90,000 to 120,000			
Copper	8.8 to 8.9	1930°	99.9	73.6	25,000 to 50,000	.320	555	14¢
Lead	11.2 to 11.4	620°	8.3	8.5	1,600 to 2,400	.410	709	4½¢
Tin	6.9 to 7.3	446°	15.0	14.5	3,000 to 5,000	.263	455	25¢
Zinc	6.8 to 7.2	774°	29.0	19.0	5,000 to 20,000	.258	446	4¾¢
Aluminum	2.56	1100°	63.0	38.0	12,000 to 23,000	.093	160	30¢
Bronze	8.7	1550°	6.5		29,000 to 60,000	.313	541	20¢
Brass	8.4		22.0	23.6	30,000 to 40,000	.300	519	13¢

ALLOYS.

Mixed metals give us alloys, many of which possess useful and valuable qualities not found in the pure metals. The ancients were skilled in making bronze and brass, and many of their products cannot be surpassed at the present day.

In general the alloys of copper with tin are known as bronze, and with zinc as brass, but zinc is frequently added to bronze to cheapen it or change the color, and tin is often added to brass to harden it, so that the line between them cannot be sharply drawn.

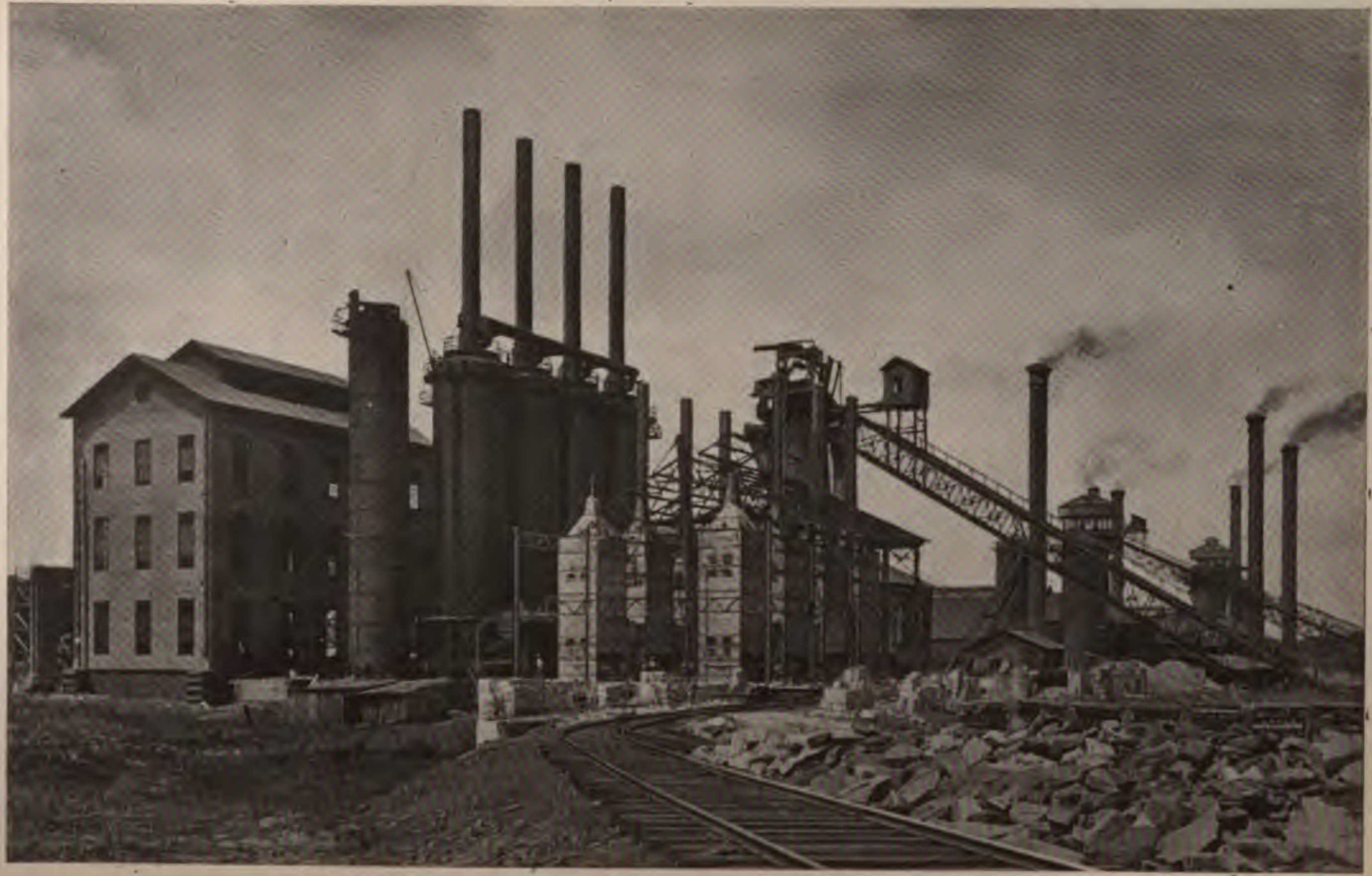
There are countless combinations of metals, but only a few are of general importance. The table given includes most of these with their approximate composition, although each foundry has its own special mixtures. In making alloys, the most infusible metal is melted first, and the others are dropped into the crucible in small lumps, the most volatile being added last. A layer of charcoal is frequently thrown on the surface of the metal to prevent oxidation. In many alloys the metals begin to separate on standing, in which case it is necessary to mix well and pour at as a low temperature as possible, so that the casting will solidify quickly. This is helped by casting in iron moulds. Some metals can not be alloyed in all proportions; thus copper will take up only a small proportion of lead.

To produce finest quality alloys only pure metals can be used, as small amounts of impurities have a very decided effect, just as in the case of iron and copper. The method of making is also important in determining the quality of an alloy. In general alloys which are to be worked into sheets, tubes and wires must be more pure than those required for castings. A small proportion of lead is said to help the rolling qualities of brass, and a very small percentage of phosphorus in bronze makes it more fluid and free from blow holes. The alloys of metals with mercury are called amalgams. One method of extracting metallic gold from its ores is amalgamation, and the effect of amalgamating the zinc in batteries is well known. Formerly alloys were thought to be chemical combinations of metals, but now it is generally considered that they are simply mixtures of metals, sometimes being solidified solutions in each other.

TABLE OF ALLOYS.

Approximate Percentage Composition by Weight.

NAME.	Copper.	Tin.	Zinc.	Lead.	Other Metals.	USES AND REMARKS.
Gun metal	91	9				Ordnance, bearings, castings
Bell metal	75	25				Bells, gongs; rather brittle
Bronze coin	95	4	1			Coins, medals
Phosphor bronze	92½	7			½ Phosphorus	Strong castings, heavy bearings
Manganese bronze	89	10			1 Manganese	Propeller blades, pumps. It is non-corrosive and very strong
Aluminum bronze	90				10 Aluminum	Very high tensile strength
Valve metal (best)	88	12	2			Sometimes called "composition"
Valve metal	83	2	15			Cheaper valves, cocks, etc.
Bearing metal	77	8		15	Trace of Phosphorus	Heavy bearings, used on railroads
Brass (common)	66⅔		33⅓			Sheets, wire, tubes, pipe fittings
Muntz metal	60		40			Bolts, nuts; malleable at red heat
Delta metal	56		42		2 Iron	Strong sheets, etc; "Tobin bronze" is a delta metal with a little tin and lead added.
Brazing metal (soft)	50	12½	37½			Low melting point
Brazing metal (medium)	50		50			For copper work
Brazing metal (hard)	75		25			Strongest
German silver	60		20		20 Nickel	Ornaments, resistance wire; composition variable
Fusible plug		10		86	4 Bismuth	For steam boilers
Common solder		50		50		
Fine solder		66⅔		33⅓		
Babbitt's metal	3	89			8 Antimony	The original Babbitt; for bearings
Babbitt's metal				80	20 Antimony	Commonly called Babbitt; used for repair work on bearings
Pewter		80		18	2 Antimony	Plates, mugs, etc.; composition variable
Britannia metal		90			10 Antimony	Table wear, ornaments; composition variable
Type metal				80	20 Antimony	Type and lithograph
Regulus metal				88	12 Antimony	Acid cocks, valves, etc. Sometimes called white metal



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FOUNDRY WORK

PART I

Foundry work is the name applied to that branch of engineering which deals with melting metal and pouring it in liquid form into sand molds to shape it into castings of all descriptions.

In the manufacture of modern machinery three classes of castings are employed, each one having its individual physical properties, such as strength, toughness, durability, etc. These castings are made from gray iron, copper alloys, *i. e.*, brass, bronze, etc., and mild steel. By far the greatest number of castings made are of gray iron, that is, iron which may be machined directly as it comes from the mold without any further heat treatment.

The main purpose of this book is to explain the underlying principles involved in making molds for gray iron castings, and the mixing and melting of the metals for such castings.

There are two other forms of iron castings. These are chilled iron, used for rolling mill rolls, car wheels, etc., and malleable iron, used for certain lines of builders' and manufacturers' hardware These are not dealt with in detail because they are rather specialities in the trade, whereas there are few towns of importance in this country in which there is no gray iron foundry.

The chapters on brass founding and steel casting will emphasize only those features of the methods used which differ from iron foundry practice.

The chapter on shop management is intended to set students thinking on this subject; because the whole trend of modern shop practice is toward specialization and system in handling every department of the work, in order to increase efficiency and reduce cost.

IRON MOLDING

There are four main branches in gray iron molding: green sand work, core work, dry sand molding, and loam work.

Green sand molding is the cheapest, quickest method of making the general run of castings. Damp molding sand is rammed over the pattern. Suitable flasks are used for handling the mold. When the pattern is withdrawn the mold is finished and the metal poured while the efficiency of the mold is still retained by reason of this dampness. The mold may be poured as soon as made. In case of necessity the mold may be held over a day or more depending upon its size. If the sand dries out, the mold should not be poured.

Core making supplements molding. It deals with the coustruction of separate shapes in sand which form holes, cavities, or pockets in the castings. Such shapes are called cores. They are held firmly in position by the sand of the mold itself. Core sand is of a different composition from molding sand. It is shaped in wooden molds called core boxes. All cores are baked in an oven before they can be used. The whole detail of their construction is so different from that of a mold, that core making is a distinct trade. A trade, however, that is generally considered a stepping stone to that of molding. Boys usually begin to serve their time in the core shop.

Dry sand is the term applied to that class of work where a flask is used, but a layer of core sand mixture is used as a facing next to pattern and joint, and the entire mold is baked before pouring. This drives off all moisture and gives hard, clean surfaces to shape the iron. It is used where heavy work having considerable detail is to be cast, or where the rush of metal or the bulk of it might injure a mold of green sand. Dry sand molds are usually made up one day, baked over night, and assembled and cast the next day.

Loam work is the term applied to molds built of bricks carried on heavy iron plates. The facing is put on the bricks in the form of mortar and shaped by sweeps or patterns depending upon the design of the piece to be cast. All parts of the mold are baked, rendering the surfaces hard and clean. After being assembled, these brick molds must be rammed up on the outside with green sand in a pit or casing to prevent them bursting out under the casting pressure. Simple molds can be made up one day, assembled, rammed up and poured the next but it usually takes three or four days and sometimes as many weeks to turn out a casting.

Loam work is used for the heaviest class of iron castings for which, on account of the limited number wanted, or the simplicity of the shape, it would not pay to make complete patterns and use a flask.

In some cases the intricacy of the design makes a pattern necessary, and size alone excludes the use of sand and flasks.

No hard and fast rules exist for the selection of the method by which a piece will be molded. Especially with large work the question whether it shall be put up in green sand, dry sand, or loam, often depends upon local shop conditions. The point to consider is: How can the best casting for the purpose be made for the least money, considering the facilities at hand to work with?

MATERIALS

Before taking up the making of molds, let us consider briefly the materials used, where they are obtained, and what is their particular service in the mold. Also we shall describe the principal tools used by the molder in working up these materials into molds.

There are three general classes of materials for molding kept in stock in the foundry. These are:

SANDS

- Molding sands
    - Light
    - Medium
    - Strong
- Free sands
    - Sharp or Fire
    - Beach sand

FACINGS

- Graphite
- Charcoal
- Sea coal

MISCELLANEOUS

- Fire clay
- Parting dust
    - Burnt sand
    - Charcoal
    - Partainol
- Core binders

SANDS

All sands are formed by the breaking up of rocks due to the action of natural forces, such as frost, wind, rain, and the action of water.

Fragments of rocks on the mountain sides, broken off by action of frost, are washed into mountain streams by rainfall. Here they grind against each other and pieces thus chipped off are carried by the rush of the current down into the rivers. Tumbled along by the rapid current of the upper river, the sand will finally be deposited where the stream flows more gently through the low land stretches below the hills. Here the slight agitation tends to cause the finer sand and the clay to settle lower and lower down in the bed. Thus we find beds that have been formed in ages past; possibly with a top soil formed over them, so long have they been deposited. But on removing the top soil we find gravel or coarse sand on top; this merges into finer sand and this again finally into a bed of clay.

Rocks, however, are very complex in their composition, and sands contain most of the elements of the rocks of which they are fragments. For this reason molding sands in different parts of the United States vary considerably.

A good molding sand should, first of all, be refractory, that is, capable of withstanding the heat of molten metal. It should be porous to allow the escape of gases from the mold. It should have a certain amount of clay to give it "bond" or strength, and should have an even grain. All of these properties will vary according to the class of work for which the sand is used.

The two important chemical elements in such sands are silica, which is the heat-resisting element, and alumina, or clay, which gives the bond. Other elements which are found in the molding sands are oxide of iron, oxide of lime, lime carbonate, soda potash, combined water, etc. The following analyses, by W. G. Scott, will give an idea of the proportion of these elements in the different foundry sands:

CHEMICAL SYMBOLS	FIRE SAND	MOLDING SANDS				CORE SAND
		Iron Work			Brass	
		Light	Medium	Heavy	Light	
a. Silica SiO_2	98.04	82.21	85.85	88.40	78.86	85.50
Alumina (clay) Al_2O_3	1.40	9.48	8.37	6.80	7.89	2.65
Iron oxide Fe_2O_3	.06	4.25	2.32	2.00	5.45	.85
Lime oxide CaO	.20	....	.50	.78	.50	....
b. Lime carbonate $CaCO_3$	....	.68	.29	....	1.46	2.65
Magnesia MgO	.16	.32	.81	.50	1.18	4.27
Soda Na_2O	....	.09	.10	....	.13	.04
Potash K_2O	....	.05	.03	....	.09	.04
Combined water H_2O	.11	2.64	1.68	1.73	3.80	2.00
Organic matter		.28	.15	.04	.64	1.00
Specific gravity	2.592	2.652	2.645	2.630	2.640	
Degree of fineness		85.	66.	46.	95.	

Silica alone is a fire-resisting element, but it has no bond. These other elements help in forming the bond. But under heat, silica combines and fuses with them, forming silicates. These silicates melt at a much lower temperature than does free silica. Therefore with sands carrying much limestone in their make up, or those containing much oxide of iron, soda potash, etc., the molten iron will "burn in" more, making it more difficult to clean the castings.

The limestone combinations also go to pieces under heat, tending to make the sand crumble, which may result in dirty castings.

The proportions given in the above table must not be considered as absolutely fixed, for no two samples of sand, even from the same bed, will analyze exactly alike. The table is instructive, however, because it shows the reason why the different sands are especially adapted to the use to which they are put in practice; as for example:

Fire Sand is used in the daubing mixture for repairing inside of cupola and ladles, and should be in the highest degree refractory, and should contain as little matter as possible that would tend to make it fuse or melt.

Light Molding Sand is used for castings such as stove plate, etc., which may have very finely carved detail on their surfaces, but are thin. The sand should be very fine to bring out this detail; it must be strong, *i. e.*, high in clay, so that the mold will retain every detail as the metal rushes in. On the other hand, the work will cool so quickly that after the initial escape of the air and steam there will be very little gas to come off through the sand.

Medium Sand is used for bench work, and light floor work, making machinery castings having from $\frac{1}{2}$ to 2-inch sections.

These will have less fine detail, so the sand may be coarser than in the previous case. The bond should still be fairly strong to preserve the shape of the mold, but the tendency of the large proportion of clay to choke the vent will be offset by the larger size of the grain. This vent must be provided for because the metal will remain hot in the mold for a longer time and will cause gases to form during the whole of its cooling period.

Heavy Sand is used for the largest iron castings. Here the sand must be high in silica and the grain coarse because the heat of the molten metal must be resisted by the sand and gases must be carried off through the sand for a very long time after pouring. The amount of bond or clay must be small or it will cause the sand to cake and choke these gases. The detail is generally so large that the lack of bond is compensated for by the use of gaggers, nails, etc. The coarse grain is rendered smooth on the mold surface by careful slicking.

Core Sand, often almost entirely surrounded by metal, must be quite refractory but have very little clay bond. This bond would make the sand cake, choking the vent, and render it difficult of removal from a cavity when cleaning the casting. Compared with medium molding sand it shows higher in silica although having less than half the proportion of alumina.

Sands having practically no clay in them are called *free sands.* Of these there are two kinds in use, *river sands* and *beach sands.*

The grains of river sand retain the sharp fractured appearance of chipped rock, and these little sharp grains help much in making a strong core because the sharp angular grains interlock one with another. River sand is used on the larger core work. Beach sand is considerably used in coast sections because it is relatively inexpensive, but its grains are all rounded smooth by the incessant action of the waves. It will pack together only as will so many minute marbles. For this reason it is used only for small cores.

FACINGS

Foundry facing is the term given to materials applied to or mixed with the sand which comes in contact with the melted metal. The object being to give a smooth surface to the casting. They accomplish this in two ways: 1st, by filling in the pores between the sand, thus giving a smooth surface to the mold face before the metal is poured; 2nd, they burn very slowly under the heat of the metal, forming a thin film of gas between sand and iron during the cooling process. This prevents the iron "burning into" the sand and causes the sand to separate from the casting when cold.

Different forms of carbon are used for this purpose because carbon will glow and give off gases, but it will not melt. The principal facings are *graphite, charcoal,* and *sea coal.*

Graphite is a mineral form of carbon. It is mined from the earth and shipped in lumps which are blacker than coal and soft and greasy like a lump of clay. The purest graphite comes from the Island of Ceylon, India. There are several beds, however, in the coal fields of North America.

Charcoal is a vegetable form of carbon. It is made by forming a shapely pile of wood, covering this over with earth and sod, with the exception of four small openings at the bottom and one at the top. The pile is set on fire and the wood smoulders for days. This burns off the gases from the wood, leaving the fibrous structure charred but not consumed. Charcoal burning is done in the lumbering districts. The charcoal for foundry facings should be made from hard wood.

Although sea coal contains a high per cent of carbon, it is less pure than the other facings and will give off much more gas. Sea coal is made from the screenings from the soft coal breakers. The coal should be carefully selected by the manufacturer and be free from slate and very low in sulphur.

All facings are manufactured by putting the raw materials through a series of crushers, tumbling mills or old-fashioned burr stone mills, and then screening them. The finest facings are bolted much as flour is.

In the shop the molder distinguishes between facings or blackings, and facing sand. The former consists of graphite or charcoal, and is applied to the finished surface of a mold or core. The latter is the name given to a mixture of new sand, old sand, and sea coal which in the heavier classes of work form the first layer of sand next the pattern.

The use of the different facings will be clearly seen from the following table:

MATERIAL	USES	ACTION
Charcoal.	Good facing for light molds; dusted on from bag after pattern is drawn.	Burns at low enough temperature to be effective before thin work cools.
	Mixed with molasses water for wash for small cores and dry sand work.	
	Mixed with some graphite and clay wash for blacking for heavy dry sand and loam work; slicked over with tools.	Resists moisture; prevents sand surfaces from sticking together.
	May be used as a parting dust on joint of bench molds.	
Graphite.	Good facing for bench molds; dusted on from bag; good for medium and heavy green sand work. Applied with camel's hair brush, and slicked over with tools.	Good on heavier green sand because it is more refractory than charcoal, but still forms gas enough to keep metal from burning into sand.
	For heavy blacking for dry sand and loam work. See above.	
Sea Coal.	Mixed with facing sand in proportions 1—6 to 1—12. See section on molding.	Helps to force vents through sand when mold is first poured, and prevents strong sand of the facing from caking, because it continues to throw off gas after casting has solidified.

MISCELLANEOUS MATERIAL

Fire Clay comes from the same source that sand does. It is almost pure oxide of alumina, which is separated out from the sand by a combination of the chemical and mechanical action of the waters of the streams. Fire clay has traces of the other impurities mentioned in the analysis of molding sands. It is found in the lowest strata of the deposit beds.

It is used to mix with fire sand in the proportion of 1 to 4 as the daubing mixture for cupola and ladles.

Clay Wash—fire clay and water. The test for mixing this is as follows: Dip the finger into the wash and then withdraw it. There should be an even film of clay deposited on the finger.

Clay wash is used as the basis of heavy blackings. It is used for wetting crossbars of flasks; breaks in sand where a repair is to be made; to wet up the dry edges of ladle linings when repairing with fresh daubing mixture; in fact, any place where a strong bond is required at some particular spot.

Parting Sands or parting dusts must contain no bond. They are used to throw on to the damp surfaces of molds which must separate one from another. They prevent these surfaces formed of high bond sands from sticking to each other.

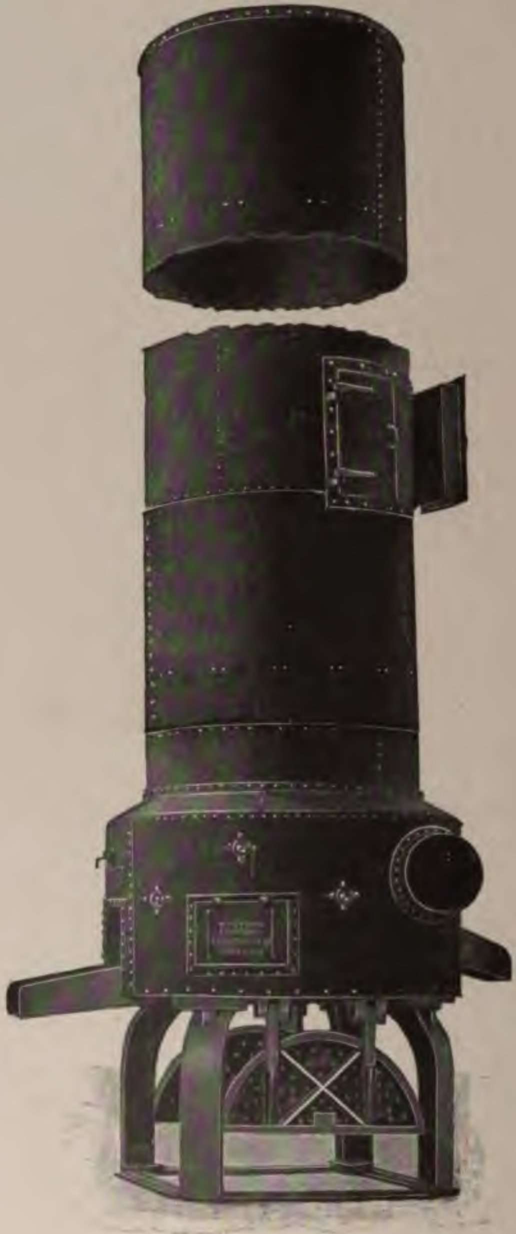
The cheapest parting sand, and by far the most commonly used, is obtained by putting some burnt core sand, from the cleaning shed, through a fine sieve.

Beach sand is also used as a parting sand, but the rounded nature of its grain weakens the molding sands more than does burnt core sand.

Charcoal facing dusted from a bag makes an excellent parting dust on fine work.

A dust manufactured expressly for the purpose and called "Partainol" is the most perfect material for fine work. This is applied from a dust bag. It is not only useful for sand joints, but is a great help if there is a deep lift on a pattern where the sand is liable to stick; or for a troublesome box in the core room.

Core Binders. Although the materials for this purpose, flour, rosin, oil, etc., are on the purchasing list of the general foundry buyer, for the purposes of this paper they will be explained in detail in the section on Core Work.



THE WHITING CUPOLA.

TOOLS

Under this heading only the hand tools and equipment used by the molder in putting up his mold, will be described. The mechanical appliances for reducing labor are described in a later section.

To use sand economically for molds, sets of open frames called flasks are used. ***Flasks*** consist of two or more such boxes. The lower box is called the ***drag*** or ***nowel,*** the upper box is called the ***cope.*** If there are intermediate parts to the flask they are called ***cheeks.*** Flasks are fitted with pins and sockets so that they will always register.

For small castings the molds are rammed up on benches or projecting brackets. Such work is termed bench work and the flasks are usually what are known as snap flasks. They range in size from 9 x 12 inches to 18 x 20 inches. As will be seen from Fig. 1, these flasks hinge on one corner and have catches on the diagonal corner. The advantage of the snap flask is that with but one flask any number of molds may be put up, and the flask removed as each mold is completed. There are several good snap flasks to be had on the market. Many foundries, however, make up their own.

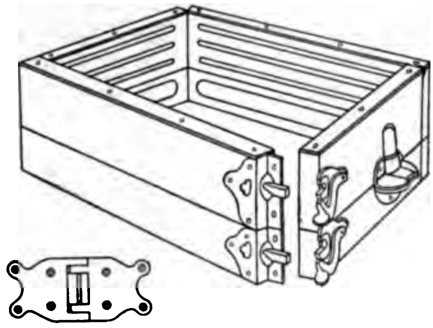


Fig. 1. Snap Flask.

Each size of flask should have at least one smooth straight board called the mold board, the size of outside dimensions of the flask. Rough boards or bottom boards of same size should be provided, one for each mold that will be put up in a day.

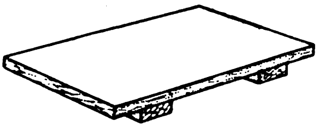


Fig. 2. Mold Board.

Boards for snap work are made from $\frac{7}{8}$ to 1 inch stuff, and should have two stiff cleats, as shown in Fig. 2, to hold them straight.

For heavier castings where the molds are made on the floor, box flasks are used made of wood or iron.

In the jobbing shop, wood flasks are more economical, as they can more readily be altered to fit a variety of patterns, while in a foundry turning out a regular line of castings, iron flasks pay because they require less repair.

Wooden flasks of necessity receive hard usage in the shop and grow weaker each time they are used. They will burn more or less each heat; they receive rough usage when the mold is shaken out; and often the flasks must be stored where they are exposed to all kinds of weather. It is economy, therefore, to build wooden flasks heavier than would be necessary if they were always to be used in their new condition.

Fig. 3 shows construction of a typical wooden flask; the sides project to form lifting handles, the ends are gained in to the sides. Through bolts hold the sides firmly in addition to the nailing. Detail of the pin is shown at A, and at B is a cast-iron rocker useful on flasks over 4 x 5 feet, to facilitate lifting and rolling over. The cleats make it a simple matter to alter crossbars. The crossbars should be not over 8 inches on centers. For more than 3-foot spans they should have short crossbars through the middle connecting the long ones. In flasks 4 feet and over there should be one or more iron crossbars and a ½-inch through bolt with good washers to clamp the sides firmly to them.

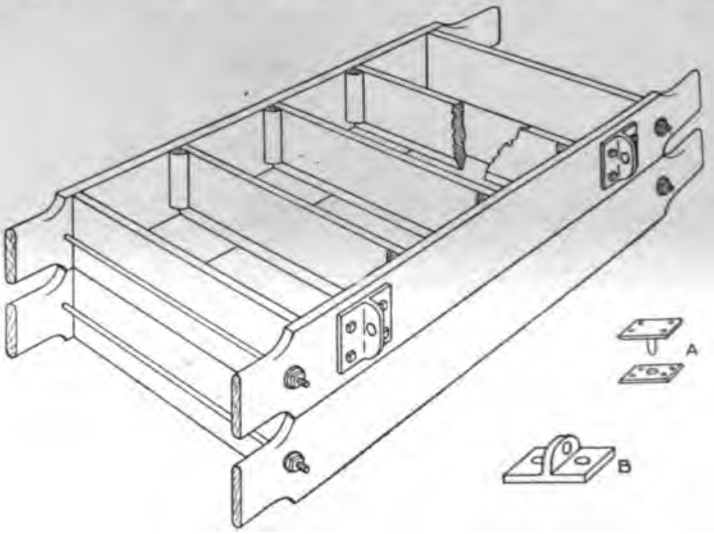


Fig. 3. Wooden Flask.

The following table shows thickness of stuff for sides and crossbars for average sizes of jobbing flasks:

Flask Sizes, 6 Inches Deep	Sides	Cross-bars	Short Cross-bars	Iron Cross-bars
Up to 24 x 24 ins.	1½ in.	1 in.		
18 ins. to 24 ins. wide to 5 ft. long	2 ins.	1 in.		1
24 ins. to 36 ins. " " 6 " "	2½ in.	1¼ in.	1 row	2
36 ins. to 48 ins. " " 7 " "	3 ins.	1½ in.	2 rows	2

N. B.—For each additional 6-inch depth of cope or drag, add 25 per cent to the thickness given.

Example. Find thickness of sides and bars in a flask 30 x 48 inches.

Length on side over 2 ft. under 5 ft. *Thickness of side* = 2 inches.

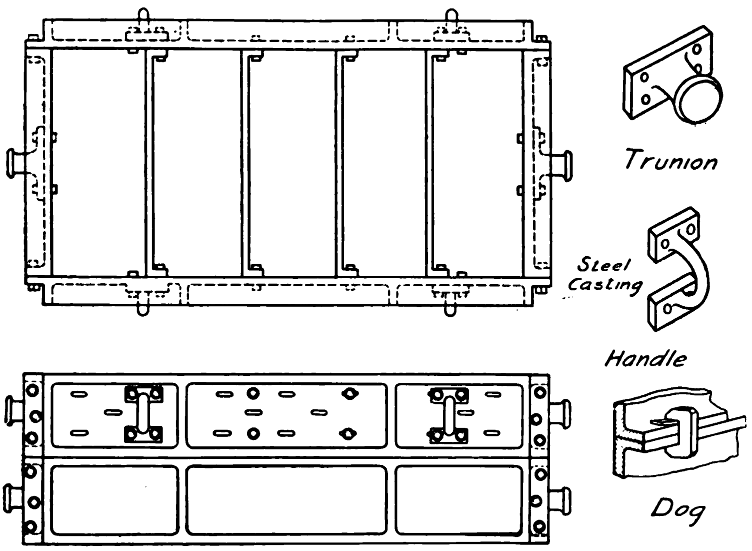


Fig. 4. Iron Flask.

Width of flask over 24 inches under 36 inches, *Thickness of crossbar* = 1¼ inches.

Fig. 4 shows the construction of a large iron flask suitable for dry sand work. The pieces of the flask are usually cast in open sand from a skeleton pattern, all holes cored in. The crossbars are cast in the same way; they have a slot in the flange instead of holes to facilitate adjusting them. Trunnions and rockers are sometimes cast on the sides in a core instead of being made separate and bolted on. Holes for pins are usually drilled through the joint flange. For pins, short iron bars are used temporarily in closing. Thickness of metal varies from $\frac{3}{8}$ to $1\frac{1}{4}$ inches according to size of flask.

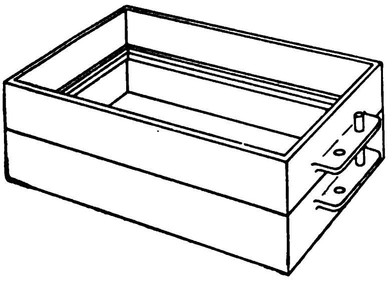


Fig. 5. Flask for Molding Machine.

Fig. 5 shows typical form of iron flask used on some molding machines. The boxes are cast in one piece. The handles serve as lugs for the closing pins. Only one pin is fixed on each box. This makes the boxes interchangeable and capable of being used for either cope or drag.

For cutting and handling loose sand the molder uses a shovel with flat blade, Fig. 6, for it is often more convenient to let the sand slide off of the side of the shovel than off of the end. This is especially true when shoveling sand into bench molds or molding machine flasks.

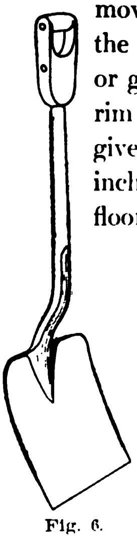


Fig. 6. Flat Blade Shovel.

The foundry sieve or riddle, Fig. 7, is used to break up and remove lumps, shot iron, nails, etc., from the sand placed next the pattern or joint. Sieves should have oak rims with brass or galvanized iron wire cloth. In ordering, the diameter of rim and number of meshes to the inch of the woven wire is given. Good sizes for the iron foundry are 16 inches to 18 inches diameter, No. 8 to 12 on bench work, No. 4 to 8 on floor work.

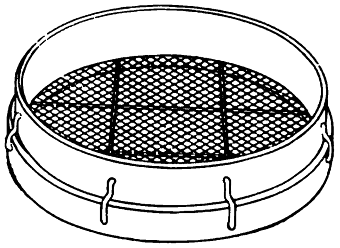


Fig. 7 Foundry Sieve.

Rammers are used for evenly and quickly packing the sand in the flask. One end is in the shape of a dull wedge, called the peen end, the other is round and flat, called the butt end. In Fig. 8, *a* is the type of rammer used on bench work; *b* is a floor rammer having cast heads and wooden shaft; *c* shows rammer made up in the foundry by casting the heads on the ends of an iron bar; *d* shows small peen cast on short rod; this is convenient for getting into corners or pockets on floor work.

In shops equipped with compressed air a pneumatic rammer is sometimes used to butt off large flasks, and for ramming loam molds in pits. See Fig. 9.

Molders' tools are designed for shaping and slicking the joint surfaces of a mold and finishing the faces of the mold itself. Except the trowels, they are forged in one piece from steel. The trowels have steel blade and short round handle which fits conveniently into the grasp of the hand. All of the tools are ground slightly crowning on the bottom. They are rocked just a little as they are worked back and forth over the sand to prevent the forward edge cutting into the surface of the mold.

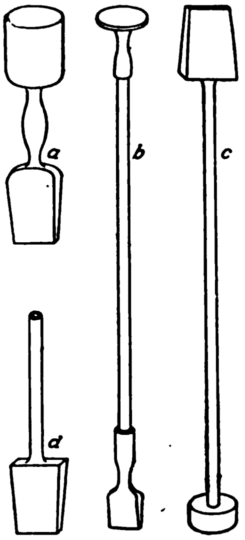


Fig. 8. Rammers.

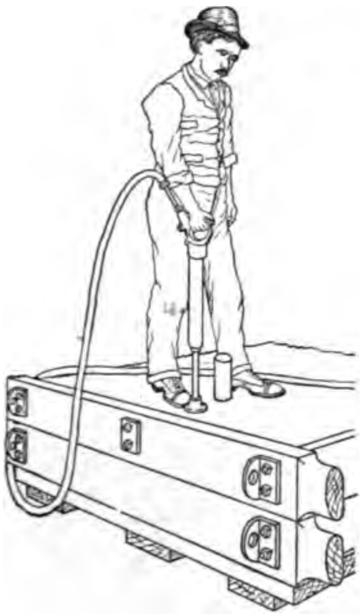


Fig. 9. Pneumatic Rammer.

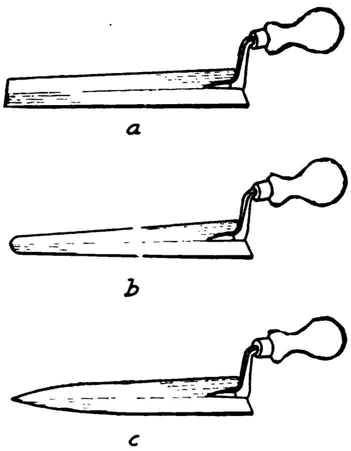


Fig. 10. Trowels.

Of the sixty or more combinations of shapes on the market, the few illustrated represent the ones most commonly used in jobbing shops.

Trowels, Fig. 10, are used for shaping and smoothing the larger surfaces of a mold. The square trowel (*a*) is convenient for working up into a square corner, and the finishing trowels (*b* and *c*) are more for coping out and finishing along the curved edges of a pattern. Trowels are measured by the width and length of blade.

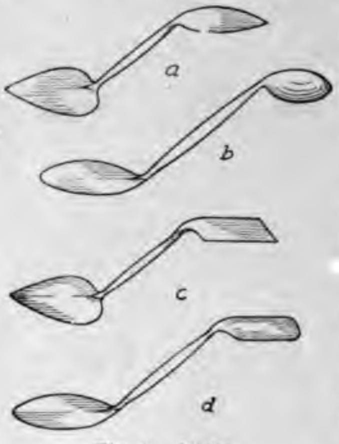


Fig. 11. Slicks.

Slicks are designated by the shape of the blade and the width of the widest blade. In Fig. 11, *a* is a heart and leaf; *b*, [illegible] and spoon; *c*, heart and square; and *d*, a spoon and bead. These are in sizes of 1 inch to $1\frac{3}{4}$ inches. They are used for repairing and slicking small surfaces

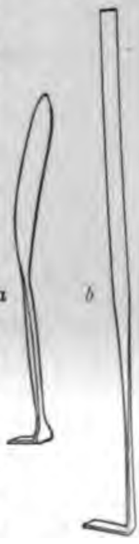


Fig. 12. Lifters.

Fig. 12 shows lifters used to clean and finish the bottom and sides of deep narrow openings; *a* is a floor lifter, made in sizes $\frac{1}{8}$ x 10 to 1 x 20; *b* is a bench lifter, sizes vary from $\frac{3}{16}$ inches to $\frac{3}{4}$ inch.

Fig. 13 shows at *a* and *b*, inside and outside square corner slicks, made in sizes of 1 to 3 inches. *c* is a half round corner, widths 1 inch to $2\frac{1}{2}$ inches; and *d* is a pipe slick made 1 inch to 2 inches. This style of tool is mainly used on dry sand and loam work.

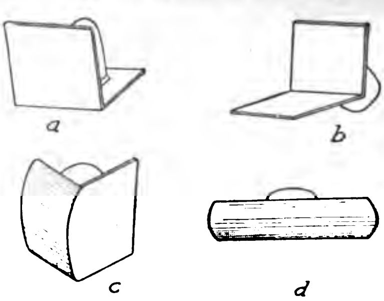


Fig. 13. Square Corner Slicks.

Swabs are used to moisten the edges of the sand about a pattern before drawing it from the mold. This foundry swab is a dangerous though useful tool. Its danger lies in a too free use of water around the mold, which may result in blow holes. A good swab for bench work is made by fastening a piece of sponge, about double the size of an egg, to a goose quill or even a pointed hardwood stick. The point will act as a guide and the water may be made to run or simply drop from the point by varying the pressure on the sponge. Floor swabs, Fig. 14, are made from hemp fiber. They should have a good body of fiber shaped to a point, and be made about 12 inches or 14 inches long. They will take up considerable water and deliver it from the tip of the point. In heavy work the swab is trailed lightly over the sand like a long bristled brush.

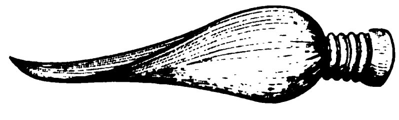


Fig. 14. Floor Swab.

Vent wires are used to pierce small holes through the sand connecting the mold cavity with the outside air. For bench work a knitting needle is the most convenient thing to use. It should have a short hardwood handle or cast ball on one end. Select a needle as small as possible, so long as it will not bend when using it.

Heavy vent rods are best made of a spring steel from $\frac{3}{16}$ inches to $\frac{1}{2}$ inch with the pointed end enlarged a little to give clearance for the body of the rod when run deep into the sand. See Fig. 15.

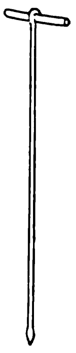


Fig. 15. Vent Rod.

Draw sticks are used to rap and draw patterns from the sand. Fig. 16 shows three kinds: (*a*) is a small pointed rod $\frac{1}{4}$ inch to $\frac{3}{8}$ inch in size, which gets its hold by simply driving it into the wood of the pattern. (*b*) is a wood screw welded to an eye for convenience. (*c*) is an eye rod with machine screw-thread, which requires a metal plate let into the pattern. The plate is called a rapping plate and is made with separate holes not threaded. Into these holes a pointed rapping bar is placed when rapping the pattern. This preserves the threads used for the drawbar.

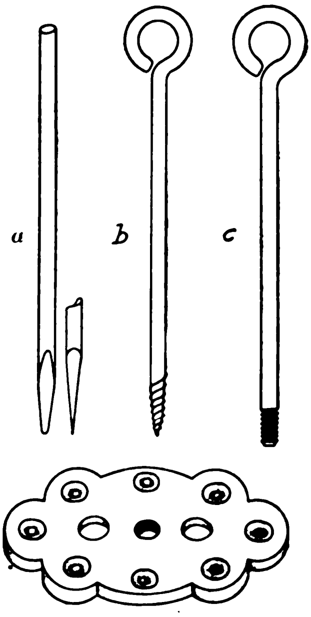


Fig. 16. Draw Sticks.

In pouring, the parts of a mold must be clamped by some method to prevent the pressure of the liquid metal from separating them, causing a run-out.

For light work a weight, shown in Fig. 17, is the most convenient. This is simply a plate of cast iron 1 inch to $1\frac{1}{2}$ inches thick, with a cross-shaped opening cast in it to give considerable liberty in placing the runner in the mold. The weights are from 15 to 40 pounds, according to size of flasks.

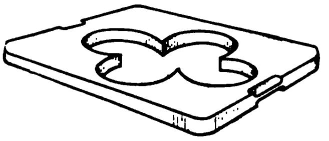


Fig. 17. Weight.

Floor flasks are fastened with clamps made of cast iron. These are tightened by prying them on to a hardwood wedge. Fig. 18 shows how wedge may first be entered and how the clamping bar is used to firmly clamp the flask. For iron flasks used in dry sand work the clamps are very short as only the flanges are clamped together. See Fig. 4. Iron wedges are used instead of wood. Often the iron bottom board is clamped on and the joint flanges bolted together before pouring.

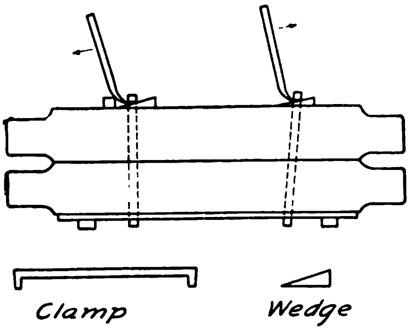


Fig. 13. Method of Clamping.

PRINCIPLES OF MOLDING

There are certain *principles* underlying iron molding which hold good in all classes of founding, and a practical understanding of these principles is necessary for good work in any line.

Aside from the fact that we generally want a mold which takes the least possible time to put up, there are three things aimed at in green sand work, these are: A *sound casting*, free from internal imperfections, such as blow holes, porous spots, shrinkage cracks, etc. A *clean casting*, free from dirt, such as slag, sand, etc. A *smooth casting*, having uniform surface free from scabs, buckles, cold shuts, or swells. The natural sands best adapted to obtain these results have already been dealt with. The methods of adding new sands vary with different classes of work. For light work the entire heap should be kept in good condition by adding a little new sand every day; for the light castings do not burn out the sand to a great extent.

On heavier work of from 50 pounds and upward, the proportion of sand next the pattern is so small compared with that used simply to fill the flask, that it does not pay to keep the entire heap strong enough for actual facing. The heap should be freshened occasionally with a cheap molding sand, but for that portion of the mold which forms the joint surface and especially that which comes in contact with the metal, a facing sand should be used.

The range of new sand in facing mixtures is

$$\left.\begin{array}{l}\text{3 to 6 New sand}\\ \text{6 to 2 Old ``}\\ \text{1 to 2 Free `}\end{array}\right\}\ \tfrac{1}{6}\text{ to }\tfrac{1}{8}\text{ Sea coal facing.}$$

These proportions, and the thickness of the layer of facing sand, vary with the weight of metal in the casting. Too much new sand tends to choke the vent and cause sand to cake; too little new sand renders facing liable to cut or scab. Too much sea coal makes sand brittle, and more difficult to work, also gives off too much gas which is liable to cause blow holes in casting. Not enough sea coal allows the sand to cake, making cleaning difficult.

To prepare foundry sand for making a mold, it must be "tempered" and "cut" through. This is now usually done by laborers.

To temper the sand, throw water over the heap in the form of a sheet by giving a peculiar backward swing to the pail as the water leaves it. Then "cut" the pile through, a shovelful at a time, letting the air through the sand and breaking up the lumps. This moistens the clay in the sand, making it adhesive and puts the pile in the best condition for working.

To test the temper, give one squeeze to a handful of sand. An excess of water will at once be detected by the soggy feeling of the sand. Now hold the egg-shaped lump between thumb and finger of each hand and break it in the middle. The edges of the break should remain firm and not crumble.

Too much moisture will make excess of steam in the mold, causing blow holes. Not enough moisture renders sand weak and apt to wash or cut.

Bearing in mind the nature of the materials we have to work with, we must now study the important *operations* involved in making a sand mold.

The sand next to the joint and over the pattern should be *sifted*. The thickness of this layer of sifted sand varies from about ¾ inch for light work, to 2 inches on very heavy work. The fineness of the sieve used depends upon the class of work. No. 16 or 12 would be used for small name plates, stove plate, etc., while No. 8 or 6 is good for general machinery work. On floor work, from 4 to 6 inches of sand back of the facing should be riddled through a No. 4 sieve to ensure more even ramming and venting.

RAMMING

The object of *ramming* is to make the sand hang into the flask and support the walls of the mold against the flow and pressure of the metal. The knack of ramming just right only comes with continued practice and comparison of results. Hard ramming closes up the vent, causing blow holes. Iron will not lay—to a hard surface. Soft ramming leaves a weak mold surface and the flow of the metal as it enters the mold will "wash" or "cut" the sand, leaving a "scab" on one part of the casting and sand holes on another. A mold rammed too soft will tend to "swell" under the pressure of the liquid metal,

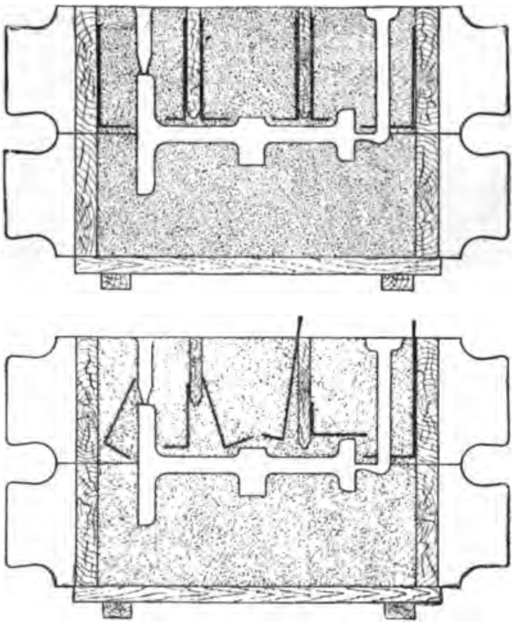


Fig. 19. Setting Gaggers.

making the casting larger than the pattern or leaving an unsightly lump on the casting. The bottom parts of a mold being under greater casting pressure must be rammed somewhat harder than the upper portions.

The joint also should be packed firmly, as it is exposed to more handling than any other part.

Crossbars are put in the cope to make it possible to lift the sand with the cope without excessively hard ramming. As an additional support for the cope sand on large work *gaggers* are used. These are L-shaped pieces of iron made from wrought or cast iron of from $\frac{5}{16}$-inch to $\frac{1}{2}$-inch square section.

The force of the sand pressing against the long leg of the gagger holds it in place and the short leg supports the sand about it. Therefore the gagger will hold best when the long leg is placed tight against the crossbar and plumb. The long leg of the gagger should not project above the level of the cope, as there is much danger of striking it and breaking in the mold after the flask is closed. Fig. 19 shows the right and the wrong ways of setting gaggers.

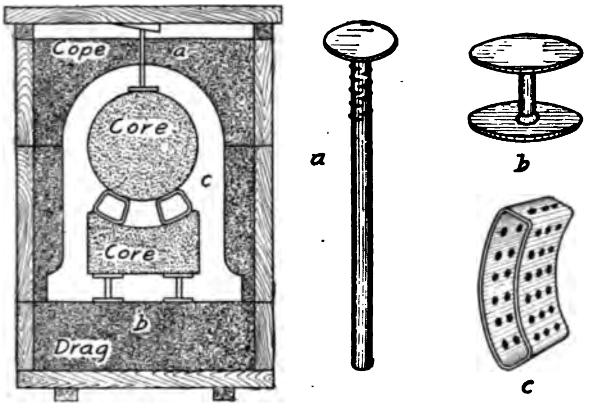


Fig. 20. Chaplets.

Chaplets should be used to support parts of cores which cannot be entirely secured by their prints which are held in the sand of the mold. Fig. 20 shows the three principal forms of chaplets used, and how they are set in the mold; (*a*) is a stem chaplet; (*b*) is a double headed or stud chaplet; and (*c*) is a form of chaplet made up of strip metal.

That portion of the chaplets which will be bedded in metal is tinned to preserve it from rusting, because rusty iron will cause liquid metal to "blow." For small cores nails are often employed for this purpose, but only new ones should be used. With the stem chaplets the tails must be cut off when the casting is cleaned—the stud chaplet becomes entirely embedded in the metal. There are now manufactured and on the market many different styles of chaplets. In selecting the size and form for a given purpose the *head* of the chaplet should be large enough to support the weight of the core without crushing into the sand and thin enough to fuse into the liquid metal. The *stem* must be small enough to fuse well to the metal and stiff enough not to bend, when hot, under its load.

VENTING

In the section on sands, reference has already been made to gases which must be taken off from a mold when it is poured. There are three forms of these: *Air*, with which the mold cavity is filled before pouring; *Steam*, formed by the action of the hot metal against the damp sand during the pouring process; and *Gases*, formed while the casting is cooling, from chemical reactions within the liquid metal and from the burning of organic matter, facings, core binder, etc., in the sands of the mold. It is of the greatest importance that these gases pass off quickly and as completely as possible. If they do not find free escape through the mold they are forced back into the liquid metal, making it "boil" or "blow." This may blow the metal out through risers and runners, or simply form numerous little bubble-shaped cavities in the casting, called "blow holes." These often form just below the skin of the casting and are not discovered until the piece is partially finished.

We cannot depend entirely upon the porosity of the molding sands, but must provide channels or *vents* for the escape of these gases.

For light work a free use of the vent wire through the sand in the cope will answer all purposes.

On castings of medium weight, besides venting with the wire, risers are placed directly on the casting or just off to one side as shown in Figs. 19 and 21. These are left open when the mold is poured and provide mainly for the escape of the air from the mold.

Heavy castings that will take some time to cool, and thus keep facings burning for a long time after the mold is poured, require venting on sides and bottom as well as top. Fig. 21 shows side vents *a a* *a a* connecting with the air through the channel *b b b* cut along joint and risers *c c c* passing through the cope. At the bottom the vents connect with cross vents *d d* run from side to side between the bottom board and edge of flask. Fig. 22 shows a mold bedded in the floor; the side or down vents connect at the top, as in previous examples, and at the bottom with a cinder bed about 2 inches thick, rammed over entire bottom of pit. The gases find escape from this cinder bed through a large gas pipe.

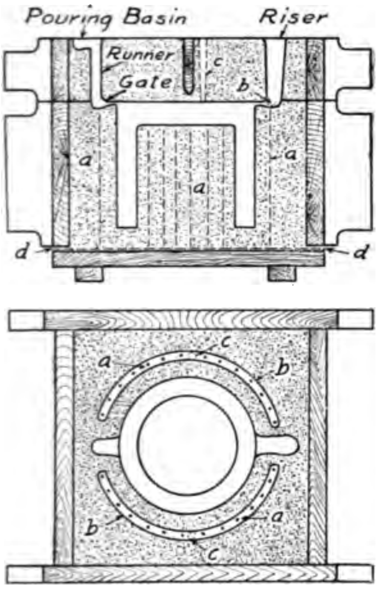


Fig. 21. Use of Risers.

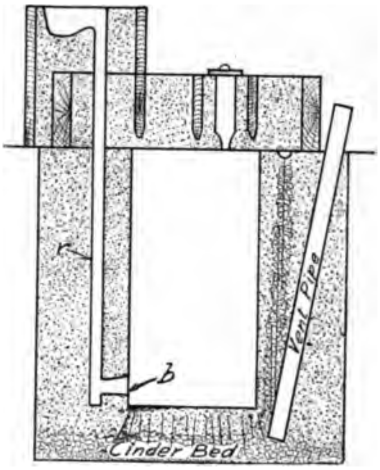


Fig. 22. Mold Bedded in Floor.

In pouring, the gas from vents should be lighted as soon as may be. The burning at the mouth of vents helps draw the gases from below and also keeps the poisonous gas out of the shop.

It is customary to keep risers closed with small cover plates when large castings are being poured so that the air in the mold will be compressed as the metal rises in the mold. This helps sustain the walls of the mold and forces the vents clear so that they will act more quickly when the mold is full. These covers are removed occasionally to watch the progress of pouring, and are entirely removed when the metal enters the risers.

GATING

Gating is the term applied to the methods of forming openings and channels in the sand by which liquid metal may enter the mold cavity. The terms *sprues* and *runners* are also used with the same meaning in some shops.

There are practically three parts to all gates—the pouring basin, the runner, and the gate. See Fig. 21. The runner is formed by a wooden gate plug made for the purpose. The pouring basin is shaped by hand on top of the cope, and the gate proper is cut along the joint surface by means of a gate cutter. In all cases the gate section should be smaller than any other part so that, when pouring, the runner and basin may be quickly flooded; also that the gate when cold will break off close to the casting and lessen the work of cleaning.

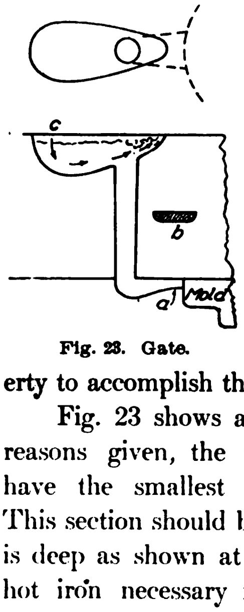


Fig. 23. Gate.

The object of gating is to fill the mold cavity with clean metal—to fill it quickly, and while filling, to create as little disturbance as possible in the metal.

The impurities in liquid metal are lighter than the metal itself, and they always rise to the top when the melted metal is at rest or nearly so. Advantage is taken of this important property to accomplish the first of the objects mentioned.

Fig. 23 shows a good type of gate to use on light work. For reasons given, the point *a* should have the smallest sectional area. This section should be wider than it is deep as shown at *b*, because the hot iron necessary for light work runs very fluid.

The runner should not be more than $\frac{5}{8}$ to $\frac{3}{4}$ inch in diameter. The pouring basin should be made deepest at point *c*, and slant upward crossing the runner. When pouring, the stream from the ladle should enter at *c*, flood the basin at once, and keep it in this condition. The current of the metal will then tend to hold back the slag, allowing clean metal to flow down the runner.

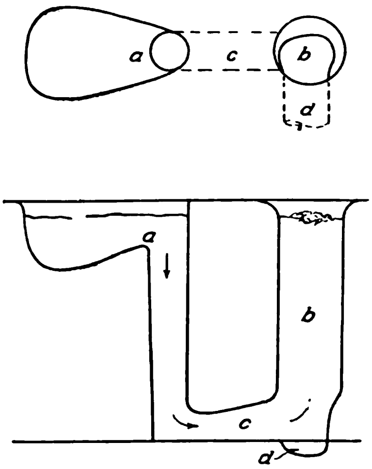


Fig. 21. Skimming Gate.

When particularly clean castings of medium weight are required, some form of skimming gate should be used. Fig. 24 illustrates one of several practical forms. They all depend for their efficiency upon the principle cited above. In the cut, *a* is the pouring basin and runner, *b* is a good sized riser placed about 3 or 4 inches from *a*, and *c* is a channel cut in the *cope joint,* connecting these two. The gate *d* should be cut in the drag side of the joint, just under the riser but at an angle of 90° or less with *c*. The metal rushing down the runner is checked by the small size of the gate and so washes any dirt or slag up into the large riser *b*. The level of metal in this riser must be sustained by sufficiently rapid pouring until the mold is filled.

In bench work and floor work, the greatest care must be used to have all parts of the gate absolutely free from loose sand or facing which will wash into the mold with the first flood of metal.

On heavy work special skimming gates are not used, for the capacity of the pouring basin is very much greater than that of the runners which can be quickly flooded and thus retain the slag. Besides this, large risers are set at the sides or directly upon the casting, to receive any loose sand or facing that washes up as the mold is being filled. Fig. 22 illustrates this type.

In regard to filling the mold quickly and quietly, the two are closely allied. The shape and thickness of the casting are the important factors in determining the number and position of the gates. Aside from the fact that the gate should never be heavier than the part of the casting to which it attaches, the actual size of the gate opening is something that the molder must learn from experience.

In arranging gates with regard to the shape of the pattern, the following points should be borne in mind. Place gates where the natural flow of the metal will tend to fill the mold quickly. Usually gate on lighter sections of casting. Select such points on the casting that the gates may be broken and ground off with least trouble. The greater the number of castings to be handled, the more important this point becomes. A study of the molding problems given will illustrate this point.

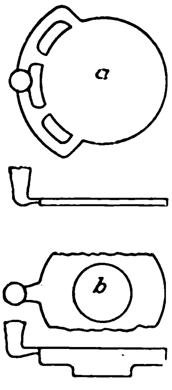


Fig. 25.
Use of Gates.

Provide enough gates to fill all parts of the mold with metal of uniform temperature. This depends upon the thickness of the work, as is illustrated in Fig. 25, by two molds having same shape at joints, but different thicknesses. In thin castings the metal tends to chill quickly, so it must be well distributed. In the cut, *a* is a plate ¼ inch thick, and should have several gates. A piece having the same diameter but heavier, would run better from one gate, see *b*, while if a bushing of this diameter is required, the best results would be obtained by gating near the bottom, as in Fig. 22. For running work at the bottom as shown in Fig. 22, the gate piece *b* is separate from the runner, and is picked into the mold after the pattern is drawn. The runner *r* should extend below the level of the gate to receive the force of the first fall of metal, which otherwise would tend to cut the sand of the gate.

SHRINKAGE HEADS

Melted metal shrinks as it cools, and this process begins from the moment the mold is filled. The surfaces next to the damp sand are the first to solidify, and they draw to themselves the more fluid metal from the interior. This process goes on until the whole casting has solidified. This shrinkage causes the grain in the middle to be coarse and sometimes even open or porous.

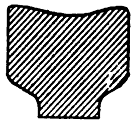


Fig. 26. Sinking of Casting.

The lower parts of a casting are under the pressure or weight of all the metal above, and so resist these shrinkage strains. The top parts, however, require the pressure of liquid metal in gates or risers to sustain them until they have hardened sufficiently to hold their shape, or they will sink as indicated by the section, Fig. 26. *Risers* mentioned in connection with securing clean metal are also required on heavy pieces to prevent this distortion and give sound metal. When used in this way they are called shrinkage heads or feeders. They should be 6 or 8 inches in diameter, so as to keep the iron liquid as long as possible, and should have a neck 2 or 3 inches in diameter, to reduce the labor required to break them from the casting in cleaning. To prevent the metal in this neck from freezing, an iron feeding rod is inserted, as in Fig. 27, and churned slowly up and down. This insures fluid metal reaching the interior. As the level in the feeder lowers, hot metal should be added from a hand ladle.

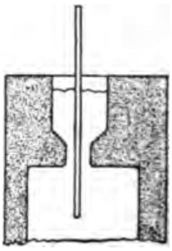
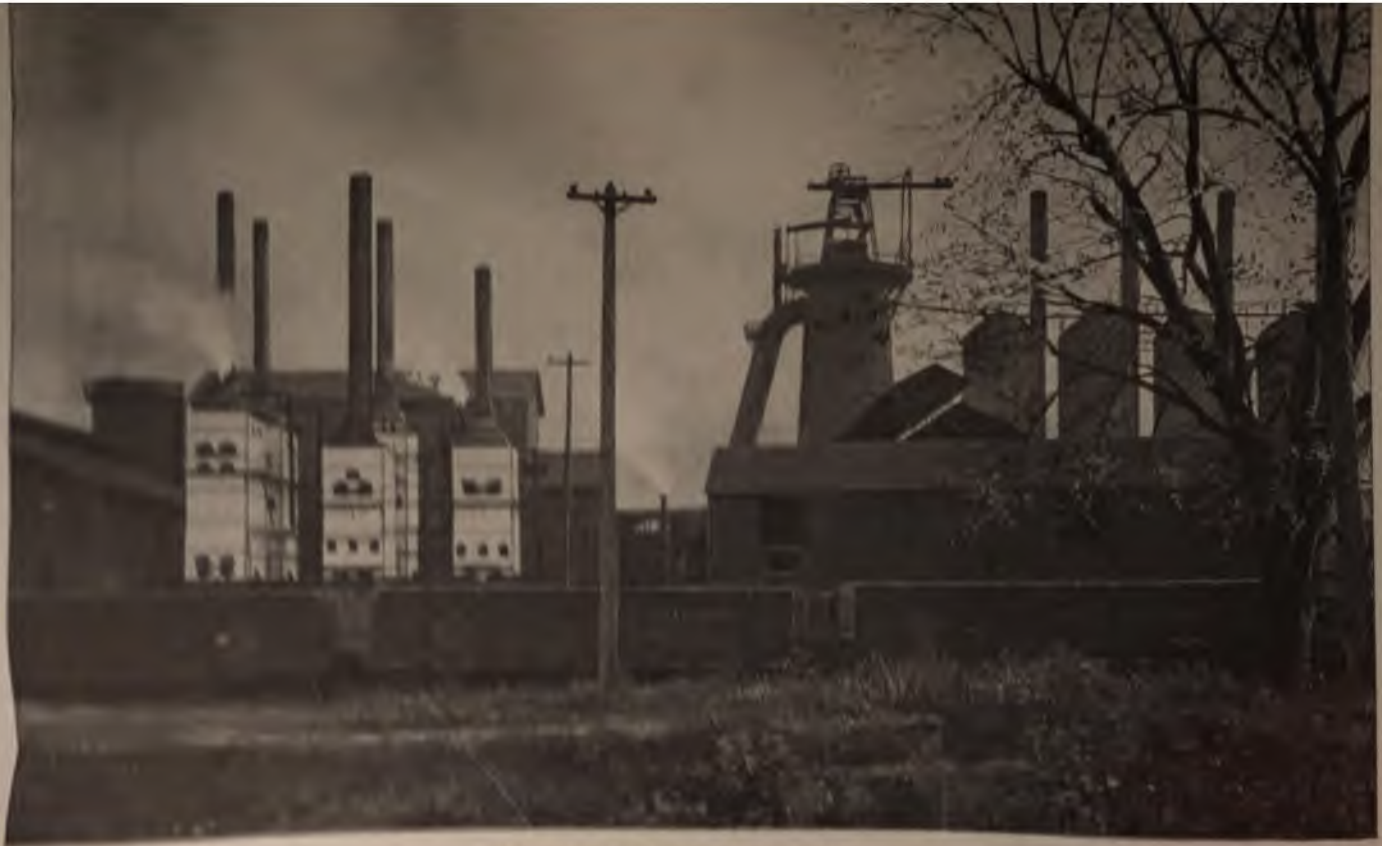


Fig. 27. Feeding Rod.



1850 HORSE POWER WHEELER BOILERS
Stewart Iron Company

PRESSURE IN MOLDS

The subject of the pressure of liquid iron mentioned repeatedly in the foregoing pages, must be dealt with by the molder in weighting his copes, strengthening flasks, securing cores, etc., but most frequently by the first of these.

Molten iron acts in accordance with the same natural laws that govern all liquids—as for example, water (see Mechanics, Part II). Iron, however, is 7.2 times heavier than water. The two laws applicable in foundry work are these: Liquids always seek their own level: Pressure in liquids is exerted in every direction.

Applying these laws: If we have two columns of liquid iron connected at the bottom, they would just balance each other. For convenience we shall leave out of our calculations the upward pressure on the gates in the following examples, for in practical work they need seldom be taken into account.

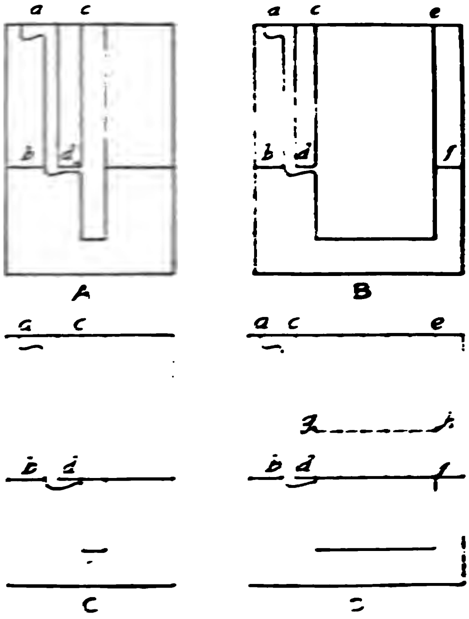


Fig. 28. [illegible]

In A, Fig. 28, suppose these columns stand 6 inches above the joint *bd*, and that column *cd* has an area of 1 sq. in. In B, suppose the area of the right hand column *def* is five times the area of column *cd*. In both cases the level with top of runner *a* will be maintained. The depth of the cavity below the joint *bdf* makes no difference in maintaining these levels. The weight of [illegible] basis of all calculations.

Now if we close the column [illegible] would require the actual weight of [illegible] pressure on surface *d*, or 6 inches [illegible] the larger area *d f* is closed over, as in D, it takes five times this weight to resist the pressure exerted upon it by the runner, or 6 inches × .26 × 5 sq. in. = 7.8 lbs. If the pattern projected 2 inches into the cope the height of the runner above the surface acting against the cope would be but 4 inches, and the pressure to be overcome would be equal to the weight of *c d g h*, equal to 4 inches × .26 × 5 inches = 5.2 lbs.

The important factors are, then, *height of runner*, and *area of mold which presses against the cope.* We can therefore state a rule: To calculate the upward pressure of molten iron, multiply the depth in inches by the weight of one cubic inch of iron (.26) and this product by the area in square inches upon which the pressure acts.

Applying the second law cited, the strains on sides and bottom of molds and upon cores is explained.

By the rule we first find the pressure per sq. in. at any given level by multiplying the depth by .26, and it is obvious that this pressure increases the lower in the mold a point is taken.

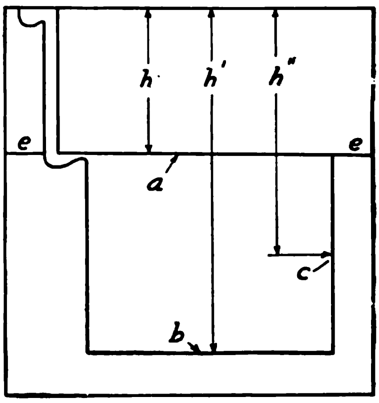


Fig. 29. Pressure of Liquids.

In Fig. 29, the pressure at *a* equals *h* × .26. This also acts against the sides at *e e*. The pressure at *b* is *h'* × .26, and is exerted sidewise and downward. The pressure at *c* is *h"* × .26. This point being half way between levels *a* and *b*, represents the average sidewise or lateral pressure on all of the sides.

If this mold then is 11 inches square, and 9 inches deep, with the pouring basin 6 inches above the joint, we have

Area of *a*, 121 sq. in.
Area of *b*, 121 sq. in.
Area of *c*, (one side), 99 sq. in.
Area of four sides, 396 sq. in.
Height of *h* = 6 in. = 1.56 lbs. per sq. in. in pressure.
Height of *h'* = 15 in. = 3.90 " " " " " "
Height of *h"* = 10½ in. = 2.73 " " " " " "

Multiplying these together, we have

Upward pressure on *a* = 188.76
Total pressure on side *c* = 270.27
Total pressure on four sides = 1081.08
Total downward pressure on *b* = 471.90

A study of these figures shows the necessity of well made flasks and bottom boards, for these must resist a greater pressure even than that required to keep the cope from lifting. They also show clearly why the lower parts of the casting will resist the pressure of the gases more and require firmer ramming than the upper portions.

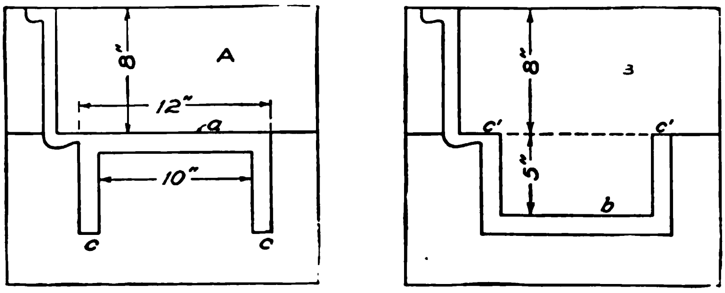


Fig. 30. Pressure of Liquids.

A difference in the way a pattern is molded may make a great difference in the weight required on the cope. Compare A and B, Fig. 30. Suppose this pattern is cylindrical in shape, we would have

Area of circle *a* (from table),—113.10
Area of circle *b* (" "),— 78.54
Area of ring *c' c'*, equal to *b* subtracted from *a*, or 34.56.

Then:

Total lift on cope A is 8 × .26 × 113.10 = 235.24 lbs.
The lift on cope B is 8 × .26 × 34.56 = 71.88 lbs.
and (8 + 5) × .26 × 78.54 = 265.46

making a total of........................337.34 lbs. on B.

Fig. 31 is an example of a core 5 inches square surrounded by 1 inch of metal, with a runner 6 inches high; we have here,

Pressure per square inch on *a* is 7 × .26 or 1.82 lbs.
" " " " " *b* " 12 × .26 or 3.12 "

The difference in these pressures is 1.30 lbs. per sq. in. Then for every foot of length in the core we must balance a lifting pressure on the bottom of the core of 5 inches × 12 inches × 3.12, or 187.2 lbs. until the metal covers surface *a*, when it will exert a counteracting downward pressure, and the strain on the chaplets will be only 60 × 1.30 lbs., or 78 lbs.

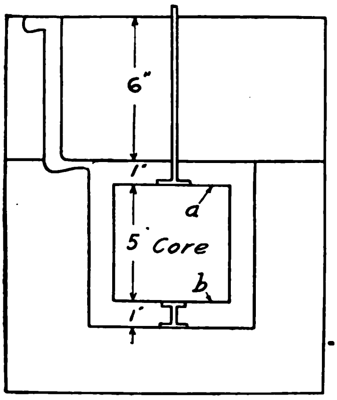


Fig. 31. Pressure of Liquids.

Some of the ordinary defects which the beginner will find on his castings are as follows:

Poured Short: The amount of metal in the ladle is misjudged with the result that the mold is not completely filled.

Blow holes come from gases becoming pocketed in the metal instead of passing off through the sand. This is due to hard ramming, wet sand, etc.

Cold Shuts form when two streams of metal chill so much before they meet, that their surfaces will not fuse when forced against each other; see Fig. 32.

Sand Holes come from loose sand or excess of facing washing into the mold cavity when pouring. They are usually bedded in the cope side of casting.

Fig. 32. Cold Shuts.

Scabs show like small warts or projections on the surface of the casting. They result from small patches of the mold face washing off. They may be caused from too much slicking, which draws the moisture to the surface of the mold, making the skin flake under the drying effect of the incoming metal.

Swells are bulged places on a casting due to soft ramming. This saves the walls of the mold too soft to withstand the pressure of the liquid metal.

Shrinkage Cracks are due to unequal cooling in the casting. They are sometimes caused by the mold being so firm that it resists the natural shrinkage of the iron, causing the metal to pull apart when only partially cold.

Warping occurs when these strains cause the casting to bend or twist, but are not sufficient to actually crack the metal.

TYPICAL MOLDING PROBLEMS

When starting to ram up a flask see that the sands to be used are well cut through and properly tempered. Select a flask large enough to hold the pattern and have at least 2 inches clear of the flask all around for bench work, and 4 to 8 inches on floor molds, depending upon the weight of the work to be cast. See that the flask is strong enough to carry the sand without racking and that the pins fit. Have the necessary tools at hand, such as sieve, rammer, slicks, etc.

Examine the pattern to be molded to see how it is drafted and note especially how the parting line runs. That part of the mold forming the surface between the parts of the flask is called the joint and where it touches the pattern this joint must be made to correspond with the parting line.

The joint of a mold will be a plane or flat surface, or it will be an irregular one. When the joint is a *flat surface* it is formed entirely by the mold board except with work bedded in the floor; there it is struck off level with a straight edge. When it is *irregular* the drag joint must be "coped out" for every mold needed; that is, shaped free hand by the molder before making up the cope; or the shape of the *cope* joint is built up *first* in a "match" frame with the cope part of the pattern bedded into it. Upon this form the drag may be packed repeatedly, receiving each time the desired joint surface without further work on the molder's part.

Our first problems in molding will illustrate these three methods of making the joint.

It is aimed to give the directions for making up molds in as concise a form as possible. The student should refer frequently to the preceding sections and familiarize himself with the reasons underlying each operation.

To make a mold having a flat joint. In the small face plate shown in Fig. 33, all of the parting line *a a a* will touch the mold board, so the joint will be flat. The draft is all in one direction from the cope side *c*, therefore all of the pattern will be in the drag. Use a snap flask for this piece.

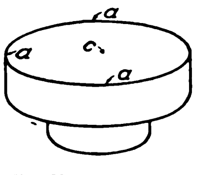


Fig. 33. Face Plate

Place a smooth mold board upon the bench or brackets. Place drag with sockets down upon this. Set pattern a little to one side of the center to allow for runner. Sift sand over this about 1½ inches deep. Tuck sand firmly around the pattern and edges of flask as indicated by arrows, Fig. 34, using fingers of both hands and being careful not to shift sand away from pattern at one point when tucking at another.

Fill the drag level full with well cut sand. With the peen end of the rammer slanted in the direction of the blows ram first around the sides of the flask to ensure the sand hanging in well, see Fig. 35, 1-2. Next carefully direct the rammer around the pattern, 3-4-5. Do not strike closer than 1 inch to the pattern with the end of the rammer.

Shifting the rammer to a vertical position, ram back and forth across the flask in both directions, being especially careful not to strike the pattern nor to ram too hard immediately over it. The student must judge by feeling when this course is properly rammed. Now fill drag heaping full of sand. Use the butt end of rammer around edges of flask first, then work in toward the middle until the sand is packed smooth over the top. With a straight-edge strike off surplus sand to a level with the bottom of flask. Take a handful of sand and throw an even layer about ½ inch deep over bottom of mold. On to this loose sand press the bottom board, rubbing it slightly back and forth to make it set well. With a hand at each end, grip the board firmly to the drag and roll it over. Remove the mold board and slick over the joint surface with the trowel. Dust parting sand over this joint (burnt core sand is good on this work), but blow it carefully off of the exposed part of the pattern. Set the wooden runner or gate plug about 2 inches from the pattern, as shown in Fig. 23.

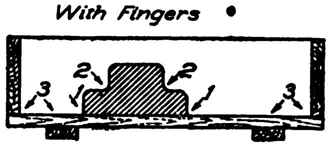


Fig. 34. Making a Mold.

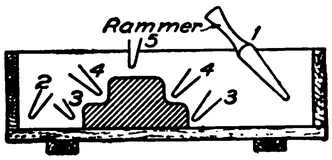


Fig. 35. Making a Mold.

In snap work the runner should come as near the middle as possible, to lessen the danger of breaking the sides, and to allow the weight to be placed square on top of the mold.

Set the cope on the drag and see that the hinges come at the same corner.

Sift on a layer of sand about 1½ inches deep. Tuck firmly with the fingers about the lower end of the runner and around the edges of the flask. Fill the cope and proceed with the ramming the same as for the drag.

Strike off the surplus sand, swinging the striking stick around the runner so as to leave a fair flat surface of sand. Drive the vent wire into the cope sand, making it strike the pattern a dozen times or more. Partially shape a pouring basin, illustrated in Fig. 23, with a gate cutter, before removing the runner. Draw the runner and finish the basin with a gate cutter and smooth it up with the fingers. Moisten the edges with a swab and blow it out clean with the bellows.

Lift the cope and repair any imperfections on the mold surface with trowel or slicks. See that the sand is firm around the lower end of the runner. Blow through the runner and all over the joint to remove all loose parting sand. Slick over the sand which will form the top surface of the gate, between the runner and the mold.

Having finished the cope, moisten the sand about the edges of the pattern with a swab. Drive a draw spike into the center of the pattern and with a mallet or light iron rod, rap the draw spike slightly front and back and crosswise. Continuing a gentle tapping of the spike, pull the pattern from the sand. If any slight break occurs, repair it with bench lifter or other convenient slick. Cut the gate and smooth it down gently with the finger; blow the mold out clean with bellows. Dust on graphite facing if castings are to be cleaned in rattler. No facing is needed if they are to be picketed. The mold should now be closed and the snap flask removed.

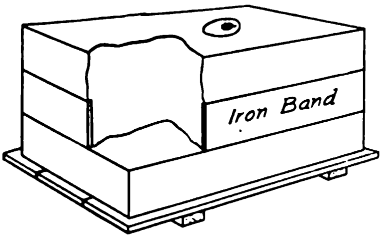


Fig. 36. Use of Iron Band.

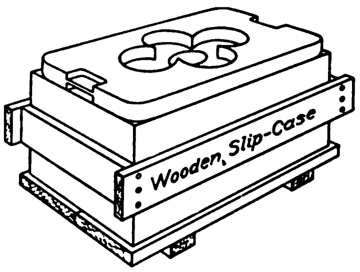


Fig. 37. Weight in Position.

There are two methods used to strengthen these molds against the casting pressure. One is to use an iron band which will just slip *inside* of the flask before the mold is packed. See Fig. 36. The other is to slide a wooden "slip case" over the mold after the snap flask is removed. See Fig. 37. In either case the weight, shown in position in Fig. 37, should not be placed on the mold until pouring time, lest by its continued pressure it might crush the sand.

A mold requiring to be coped out. The second type of joint surface mentioned above is illustrated by the method of molding the tail stock clamp shown in Fig. 38. This is a solid pattern and rests firmly upon the mold board on the edges *a a*, but the parting line *b b b* runs below these edges. The bulk of the pattern drafts down from this line, so will be molded in the drag while all above it will be shaped in the cope.

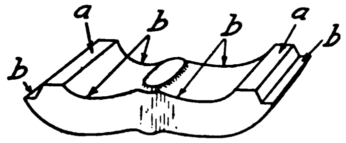


Fig. 38. Tail Stock Joint.

To mold the piece, set the pattern on the mold board planning to gate into one end. Ram the drag and roll it over as described in the last example. With the blade of the trowel turned up edgewise, scrape away the sand to the depth of the parting line, bringing the bevel up to the main level of the joint, about 2½ inches from the pattern, as shown at Fig. 39. Slick this surface smooth with the finishing trowel or leaf and spoon. This process is called coping out. Dust parting sand on the joint thus made. Be careful not to get too much at the bottom of the coping next the pattern. Pack cope, then lift same, and finish mold as directed.

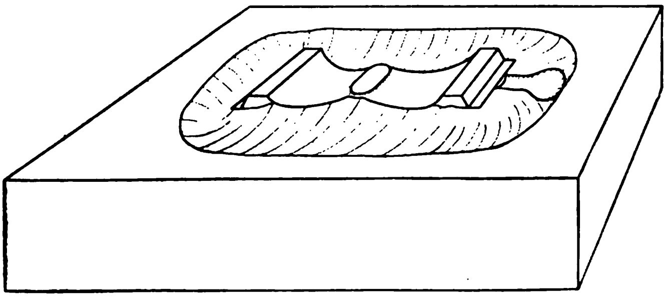


Fig. 39. Coped out Mold.

In coping out, the molder practically shapes draft on the sand of the drag. Aim to have the lower edge of the coping parallel with main joint for a short distance, and then spring gradually up to it at about the angle shown in the section, Fig. 40, at *c*, as this is the strongest shape for the sand.

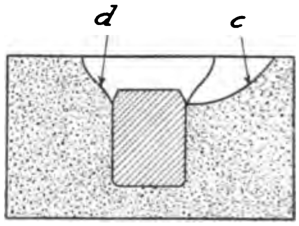


Fig. 40. Angle of Joint.

If made with an abrupt angle as in *d*, the cope sand will tend to wedge into the cut with the danger of a "drop" or break when the cope is lifted.

In many cases, more especially in floor work, an abrupt coping angle may be avoided as follows: Set wooden strips, whose thickness is equal to the depth of the desired coping, under the edges of the drag when ramming up the pattern. (Use, for example, the hand wheel shown in Pattern Making, page 58). When the drag is rolled over the sand will be level with the top of strips and pattern at *a a*, Fig. 41. Remove the strips and strike surplus sand off level with edges of drag, *b b*, and slick off the joint. Proceed with the cope in the usual manner. In gating this pattern, and wheels generally, place a small runner directly on the hub.

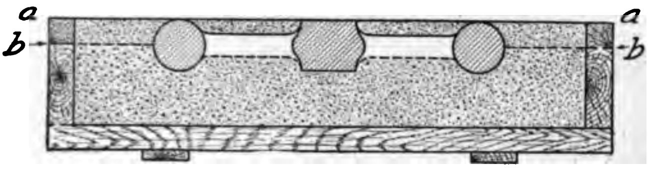


Fig. 41. Molding a Hand Wheel.

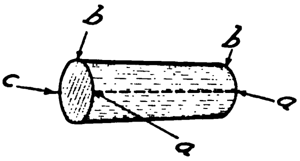


Fig. 42. Solid Bushing.

Using a sand match. The solid bushing, Fig. 42, will serve to illustrate the use of a sand match. For exercise work use only one pattern.

In practice, however, several small patterns are bedded into the same match. It is clear that in this pattern the parting line runs along the center of the cylinder, and to make a safe lift for the cope it should follow around the circumference of the ends from *a* to *c*, as shown by the heavy lines.

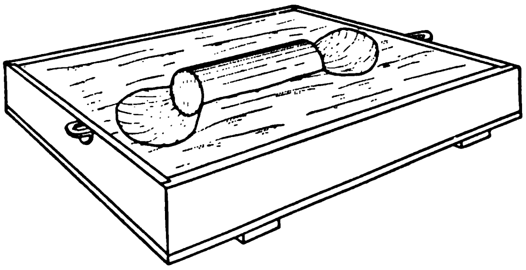


Fig. 43. Use of Sand Match.

The frame for the match is shallow, and of the same size as the snap flask with which it is used. It is provided with sockets to engage the pins of the flask. The bottom board is fastened on with screws.

Fill the match with sifted sand rammed hard. Strike off a flat joint and bed in the pattern. Cope out the ends to the lower edge of the pattern, as shown in Fig. 43, flaring it well in order to make a good lift. Slick the whole surface over smooth. Rap and lift the pattern to test the correctness of the work.

Replace the pattern. Dust on parting sand and ram drag, tucking carefully in the pocket at each end. Roll the two over. Lift off the match, and set it to one side. The pattern will remain in the drag. Dust on parting sand. Set the runner and ram cope as described. When the mold is opened and the pattern drawn, it should be set back immediately into the match, ready for use again.

On account of economy of construction in the pattern shop, irregular shaped work is often made in one piece. The molder must then decide whether it is cheaper to cope out each joint or make up a sand match. Where the number of castings required is small, or where the pattern is large, it is better to cope out. But where a number of castings is required it is cheaper to make up a sand match.

For methods of making quantities of castings and use of a more permanent match, see section on Duplicating Castings.

In the foregoing the main use of the match was to save time. It frequently happens that a pattern is so irregular in shape that it will not lie flat on the board in any position. In this case a match is absolutely necessary before the drag can be packed. For large patterns of this kind, the cope box of the flask is used to bed the pattern into instead of a separate frame. After the drag has been packed upon it this first cope is dumped, and the box repacked with the necessary gaggers, vents, runners, etc., required for casting. The first cope is then termed, not a match, but a *false cope*.

For very light wooden patterns which may or may not have irregular parting lines, the pattern maker builds up wooden forms to support the thin wood while the drag is being packed and to give the proper joint surface to the sand. This board serves exactly the same purpose as the sand match and false cope, but it is termed a *follow board*. See Pattern Making, page 137.

So far the patterns used have been made in one piece, but a flat joint is the most economical for the molder, when many castings are required. Generally such pieces as bushings, pipe connections and symmetrical machine parts are made in halves; one piece of the pattern remaining in each part of the flask when the mold is separated. There are many cases, too, where, to make a flat joint for the mold, the pattern maker can separate one or more projections so as to have the main part of the pattern in the drag and let these loose parts lift off in the cope.

The small punch frame and the gas engine piston, shown in Fig. 44, are examples of these two classes of patterns. At A, the section through the patterns shows the methods of matching them together.

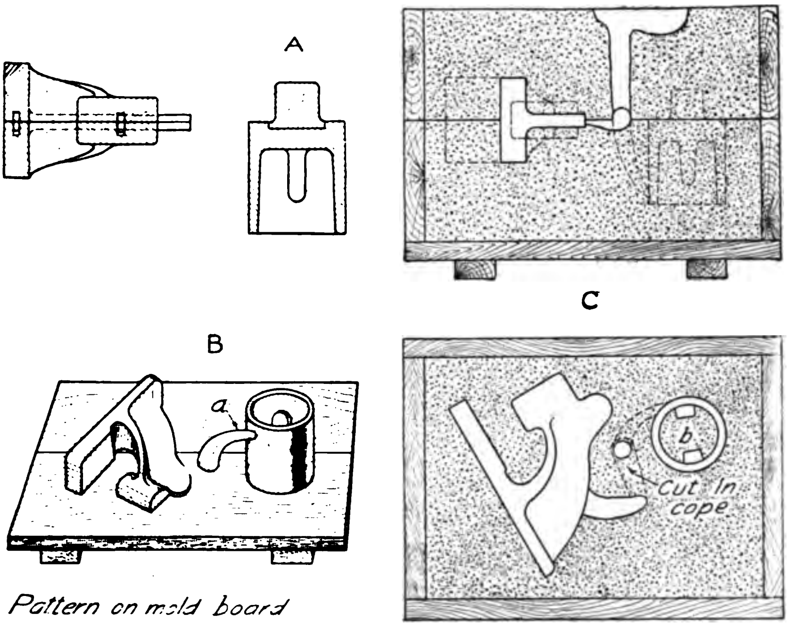


Fig. 44. Split and Loose-Piece Patterns.

B shows the drag parts of the patterns in position for molding. At C is the section through the mold and the plan of the drag showing how the gates are connected. Attention is directed to the use of the *horn sprue*—the sprue pattern is shown at *a*—by which the metal enters the mold at the bottom. If the gate were cut at the joint surface there would be danger of "cutting the sand" on top of the green sand core *b* as the metal flowed in upon it.

Some work has projections on it which lie above or below the parting line in such a way that it cannot be molded by either of the foregoing methods.

Examining the patterns for some of this work we find two entire parting lines with the pattern made to separate between the two. Such patterns require between the drag and cope an intermediate body of sand, from the top and bottom of which the two parts of the pattern may be drawn.

In small work, as illustrated by the groove pulley, this intermediate form is held in place by the sand joint of the cope and drag, and is termed a *green sand core.* A good description of the method of molding such a piece is given in Pattern Making Part I, page 60. To provide for pouring the casting a runner should be placed on the hub of the first part packed, C. Fig. 45 shows a section of the mold before either part of the pattern has been removed. Now, when the flask is rolled over to remove the final part C of the pattern, the runner is on top ready for pouring.

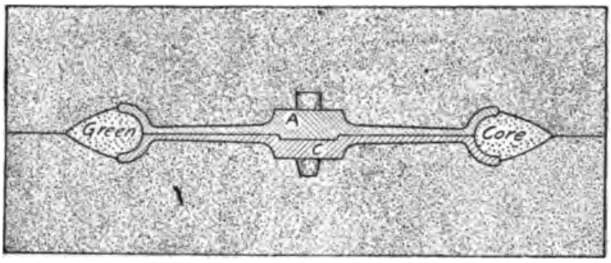


Fig. 45. Section of Mold.

Another method used does away with rolling the entire flask. A core lifting ring is first cast slightly larger in diameter than the flange of the sheave, and having a section shown in *a*, Fig. 46. The ring is set in position in the middle of the inverted *drag*, the pattern is held central inside of the ring by the recess in the mold board. Pack the drag, roll over, and remove the mold board. Tuck the green core all around and slick off the top joint of the core. Pack the cope in the usual way, lift it off, and draw the cope pattern. Now, by means of lugs cast on this lifting ring, the green core may be lifted off

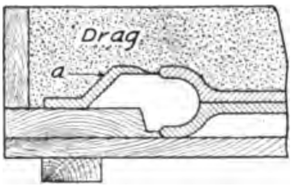


Fig. 46.

of the drag pattern, allowing it to be removed. Replace the ring, close the cope, and the mold is complete. See half-section, Fig. 47.

In larger work, where the parting planes are farther apart, this intermediate body of sand is carried in a "cheek" part to the flask, and we speak of it as three-part work.

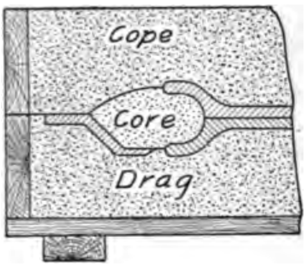


Fig. 47.

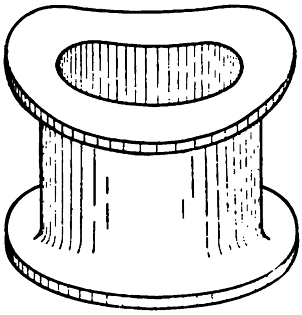


Fig. 48.

Fig. 48 shows a casting for a 10-inch nozzle, the mold for which illustrates this class of work. Here the pattern is separated just above the fillet of the curved flange. Fig. 49 gives a view of the mold, showing the way the joint is formed.

This casting should be made on the floor. Select a square flask 4 inches on a side, larger than the diameter of the flanges. The cheek should be as high as that part of the pattern which is molded in it. There should be two projecting bars on opposite sides of the cheek to support the sand, and crossbars in both drag and cope. These should be well wet with clay wash before using the boxes.

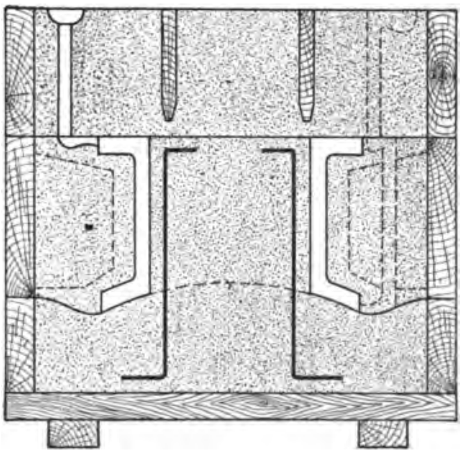


Fig. 49. Casting a Nozzle.

Set the pattern centrally inside the cheek, and place a runner stick just the height of the pattern in one corner of this box.

On account of the depth of the cheek the sand must be rammed in two courses. Sift enough facing sand into the box to cover the joint and 5 inches up around the pattern to a depth of about 1½ inches, tucking about the pattern with the fingers. Fill in about 5 inches of loose sand and before ramming tuck around the ends of the side bars, compressing the sand between the finger tips, having a hand on each side of the bar, as illustrated in Fig. 50. Now use the peen end of the floor rammer in the same general way as the hand rammer is used in bench molding. Guide the rammer around the sides of flask and bars first, then direct it toward the bottom edges of pattern. As the sand gradually feels properly packed at this level, direct the blows higher and higher up. Proceed in this way to within about 1 inch of the drag joint. Make this joint by ramming in sifted facing sand, being careful to tuck it firmly underneath the flange. Cope this joint to the shape of the curved flange.

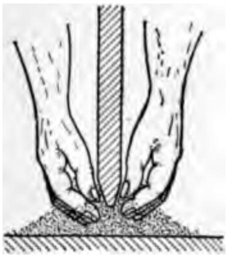


Fig. 50.

Dust on parting sand. Place the drag in position and ram it up in the usual way, only using facing sand next the joint and pattern. Place six long gaggers to strengthen the sand which forms the inside of the casting. Clamp drag to cheek and roll them over. Test, repair and sand the joint. Try the cope. The bars should clear the pattern and joint by about 1 inch. Set the cope runner about 2 inches to one side of the cheek runner and set the riser in the corner opposite. Sift on facing sand and tuck well with the fingers under the crossbars. Shovel in well-cut sand and finish packing the cope. Form a pouring basin, and vent well. Lift the cope. Draw the pattern from the cheek. Join the runners on the cope joint and connect the mold with the riser. Lift the cheek and repair it. Draw the drag pattern. All of the mold surfaces should have black lead facing brushed over them with a camel's hair brush, and this facing slicked over with convenient

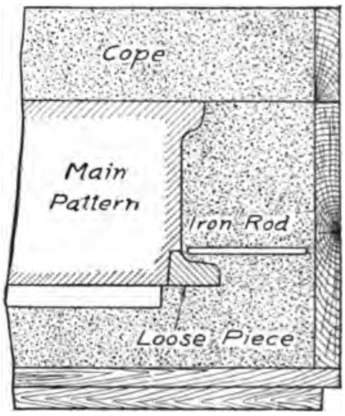


Fig. 51.

tools. Cut a gate on the drag joint. Close the cheek on the drag Close the cope on the cheek and the mold is ready for clamping.

It often happens that bosses or projections are required on a casting at right angles to the main draft lines of the pattern and below the joint surface. Examples of such cases are shown in Pattern Making, pages 61–116. In molding such a pattern care must be taken that the overhanging portion of sand shall be strong enough to support itself. Where the projection is deep, the sand should be strengthened by nails or rods as shown in Fig. [illegible] These should be wet with clay wash and set into the sand when the mold is rammed.

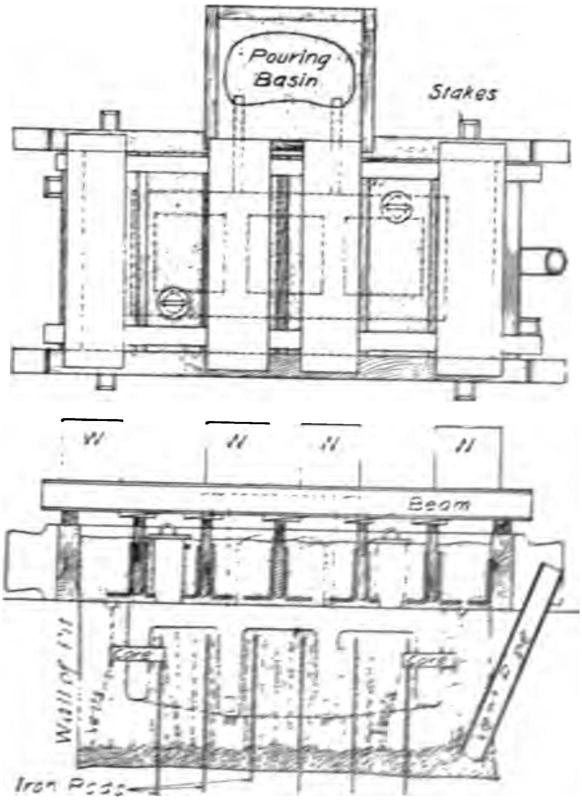


Fig. [illegible]

Owing to the development of the electric crane much of the large work is now rammed in iron flasks and rolled over, which was formerly always bedded in the floor. This method is still much used in jobbing shops to avoid making a complete large flask.

The mold shown in Fig. 52 will illustrate the principal operations involved. The casting is a flask section for a special steel ingot mold, and in design is simply a heavy plate braced on one side by flanges and ribs of equal thickness.

For convenience in ramming between the flanges, portions of the top plate of the pattern are left loose. See Fig. 53.

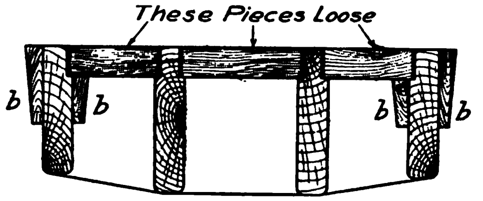


Fig. 53. Bedded-in Work.

Dig the pit for the mold 10 inches larger on each side than the pattern, and about 6 inches deeper. Having screened some hard cinders through a No. 2 riddle, cover the bottom of the pit with them to a depth of 3 inches. Ram these over with a butt rammer, and at one end set a piece of large gas pipe Put a piece of waste in the top of this to prevent its getting choked with sand. Ram a 3-inch course of sand over the cinder bed and strike it off level at the depth of the pattern from the floor line. Sift facing sand over this where the pattern will rest. Set the pattern, and with a sledge, seat it on this bed until it rests level. Remove the pattern and with the fingers test the firmness of packing all over its impression.

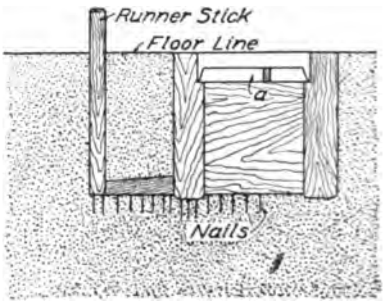


Fig. 54.

Vent these faces through to the cinder bed, and cover the vent holes with a ½-inch course of facing sand. Now replace the pattern, and bed it home by a few more blows of the sledge. The top of the pattern should now be level and flush with the floor line. Seat the runner sticks, and to prevent the sand on the bottom of the runners from cutting, drive 10-penny nails about ¾ inch apart into this surface until the heads are flush. Ram the outside of the mold the same as if in a flask, and strike a joint on top. Ram green sand between the inside webs of pat-

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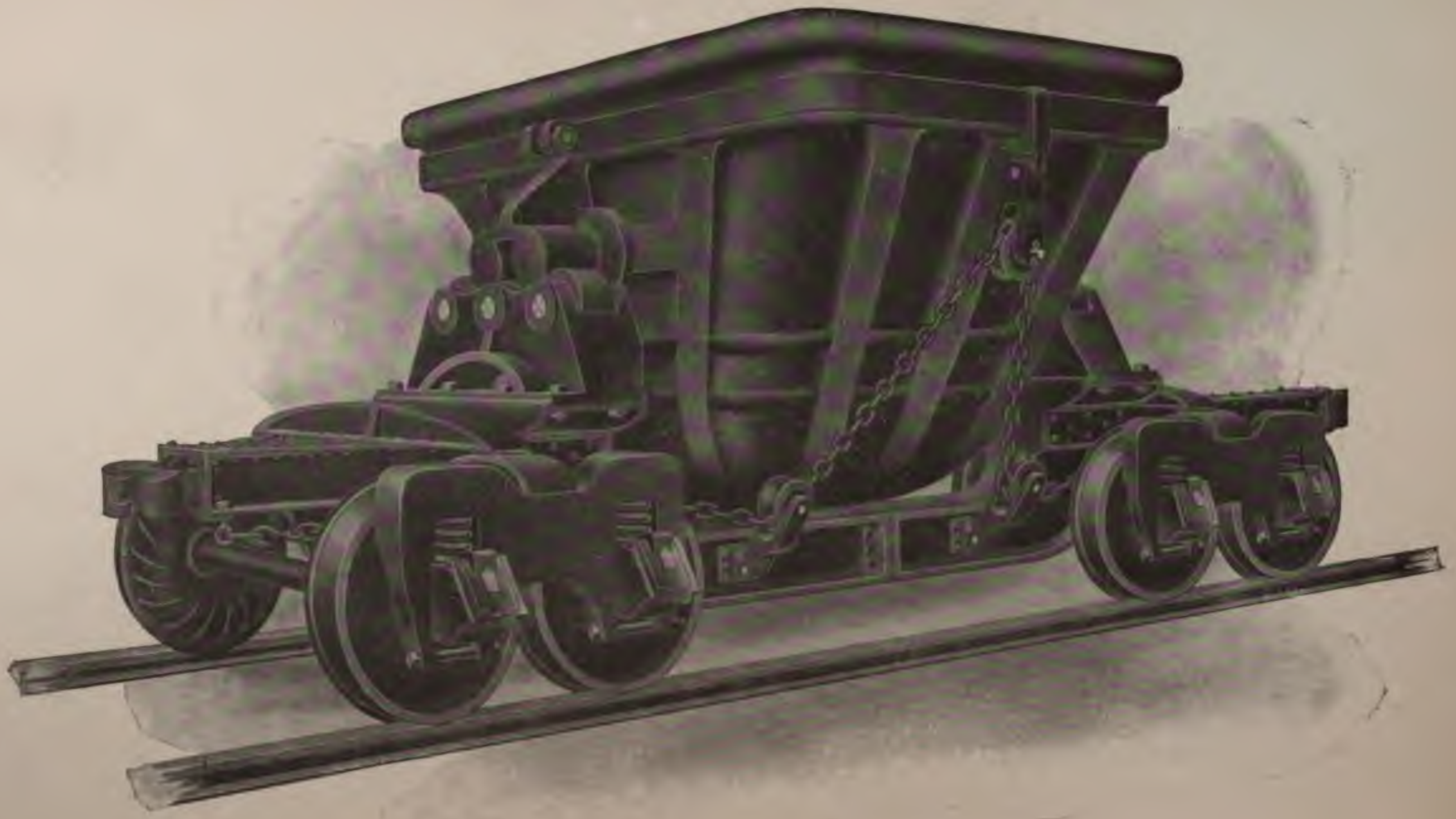


DEWHURST SLAG LADLE AND CAR DOUBLE TRUCK, SIDE TIPPING
Wellman-Seaver-Morgan Co.

tern, and strike off at the proper height with a short stick *a*, Fig. 54. Drive long rods 3 inches apart into these piers to pass through to solid sand below the cinder bed.

Vent all around the pattern, outside and inside, through to the cinder bed. On top of the inside piers cover these vent holes with facing sand, ram and slick to finish; then cover with the loose pieces of the pattern.

Try the cope and stake it in place; set the risers and vent the plugs. Ram the cope, slicking off level for about 2 inches around the top of the risers, to receive a small iron cover.

Lift the cope, repair, and face with graphite. Draw the pattern with the crane and finish the mold. Connect the outer vent holes by a channel with the vent plug. From the end of each core print *a a a a* vent through to the cinder bed and set cores. Close the cope. Set the runner box against the side of the cope and build a pouring basin with its bottom level with the top of the risers.

In weighting, great care must be exercised not to strain the cope.

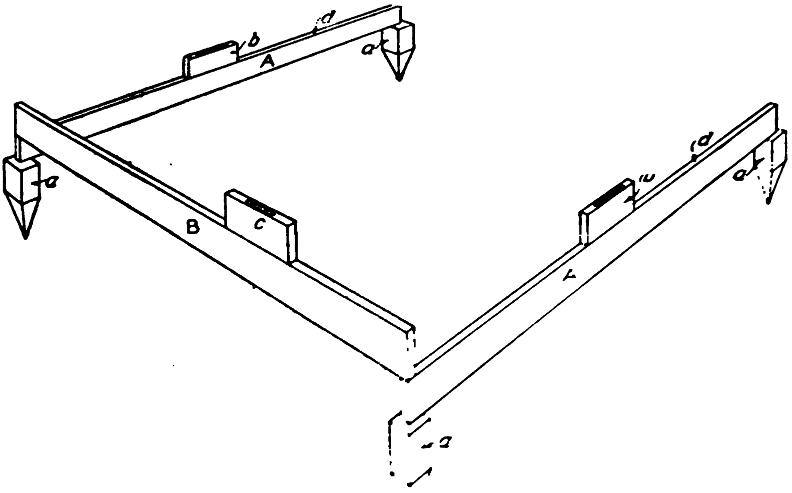


Fig 55. Leveling [illegible]

Place blocking upon the top ends of cope. [illegible] which will be stiff enough to [illegible] these. Now wedge under the beams [illegible] cope at necessary points.

There is a large class of foundry rigging, such as loam plates, crossbars and sides to iron flasks, which may be cast in open molds. As there is no "head of metal" the beds must be rammed only hard enough to support the actual weight of the metal, or it will "boil." To insure uniform thickness in the casting, the bed must be absolutely level.

Drive four stakes, *a a a a*, and rest the guide boards A A on the top of these, as shown in Fig. 55. By using a spirit level *b b*, make these level and bring them to the same height by testing with the straight edge B.

The space between the guide boards A A should be filled with well-cut sand even with their tops *d d*. Sift sand over the entire surface. Strike this sand off ⅜ inch higher than the guides, by placing a gagger under each end of the straight edge, as it is drawn over them. Tamp this extra sand to a level with the guides by rapping it down with the edge of the cross straight edge, and the bed will be as shown in Fig. 56. We can now proceed to build up to a segment of pattern, or with a sledge drive a pattern into this surface.

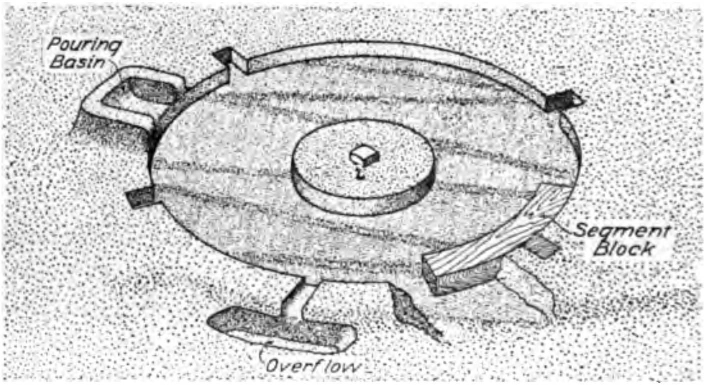


Fig. 56. Open Sand Mold.

The pouring basin should drain itself at the level of the top of mold, and an overflow may be cut on one edge to drain the casting to any desired thickness.

CORE MAKING

Reference has been made in the first part of this book to the general difference between core making and green sand work.

This, and the section on sands, the reader should review carefully.

Here, as in green sand molding, the principal material used is a refractory sand. In molding sand, however, the alumina or clay forms a natural bond in the sand. To meet the necessary requirements of cores we must use a naturally free sand as a base, and give it bond by adding some form of organic matter as a binder and then bake the core.

The most common binders are as follows:

Flour: Ordinary wheat flour is an almost universal material for this purpose. Every one is familiar with the action of this material when moistened and baked.

Rosin is a hard vegetable gum—a by-product of the manufacture of turpentine. For use as a core binder it should be reduced to a powder. It melts under the heat of the oven and flows between the grains of sand and upon cooling binds them firmly together.

Linseed Oil is made from flax seed. It acts in a way similar to rosin; a small proportion of oil together with some flour makes a very strong core.

Glue, obtained from animal hoofs, and from fish stock, is also used to some extent as a core binder. It should be dissolved in water before mixing with the sand.

A weak *molasses water* is used for tempering the sand for small cores, and *clay wash* serves the same purpose on the larger work.

There are many patent combinations of the above or similar materials put on the market as core compounds. There are two classes of these: dry and liquid compounds. The advantages claimed for them is that they are more economical, (1) because a smaller proportion of the compounds is sufficient to obtain the desired results; (2) because a large proportion of the sand may be used over and over again.

Other necessary core room supplies are:

Annealed Iron Wire, No. 6 to No. 16, and round bar iron in sizes of ¼ inch, ⅜ inch, ½ inch, ⅝ inch, ¾ inch. This material is cut to length as needed, and bedded in the core sand to strengthen the core, as will be demonstrated later.

A supply of clean *cinders* must be available for venting larger cores. Small wax tapers make good vents for crooked cores. There is also a patented wax vent for sale on the market.

As before stated, charcoal with some graphite is the principal *facing* material used on cores. It is always applied in liquid form by dipping the core or by using a flat brush having extra long bristles.

The general tools of the core room are similar to those already mentioned. A piece of iron rod very often replaces the regular rammer on account of the small size of the opening into which sand must be packed.

The trowel is the most common slick, because most of the surfaces which require slicking are flat ones formed by "striking off" after packing the box. Except in the largest work the entire face of the core is not slicked over, so a variety of small slicks is not needed.

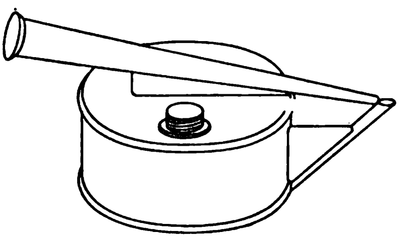


Fig. 57. Spraying Can.

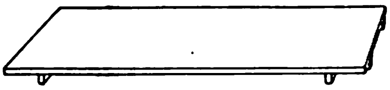


Fig. 58.

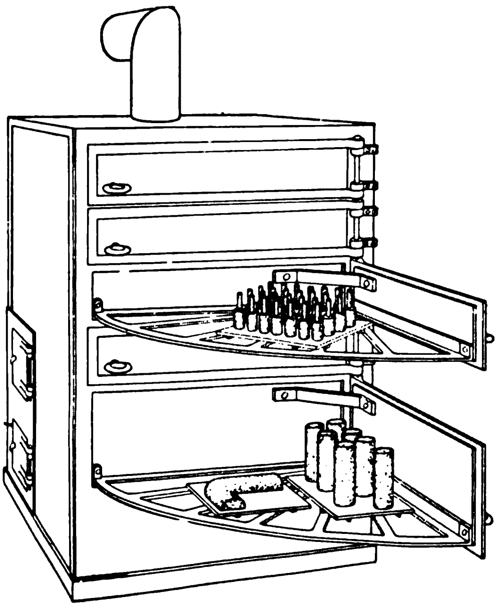


Fig. 59. Small Core Oven.

A spraying can, shown in Fig. 57, is used for spraying molasses water over small cores. Fill the can two-thirds full and blow into the mouthpiece.

Small cores are made up on a flat bench, the sand being in a small pile at the back. Larger boxes are rammed up on horses or on the floor, as is most convenient.

After being made up, cores are baked on core plates. The smaller plates are cast perfectly flat. Plates over 18 inches long are strengthened by ribs cast about 1 inch from the edge. See Fig. 58. This keeps the plate from warping and admits of its being picked up readily from a flat bench top or shelf.

Ovens are built with reference to the size of the cores to be baked. A good type of small oven is illustrated in Fig. 59. It can be run very economically with either coal or coke, and will bake cores up to 2 inches in diameter inside of half an hour. Each shelf is fastened to its own door and when open, for receiving or removing cores, a door at the back of the shelf closes the opening. This prevents a waste of heat.

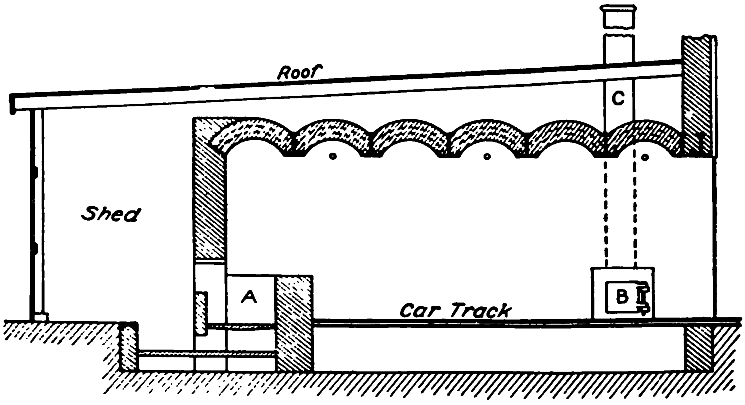


Fig. 60. Core Oven for Large Work.

Fig. 60 shows the section through an oven suitable for the largest work, including dry sand and loam molds. The fire box A is situated in one corner at the back; its whole top opens into the oven. At the floor level diagonally opposite is the flue B for conducting the waste heat to the stack C. The entire front of the oven may be opened by raising the sheet steel door. Two tracks side by side accommodate cars upon which heavy work is run into the oven. Fig. 61 shows a good form of cast-iron car. The wheels are designed on the roller principle to make it easier to start the car when heavily loaded,

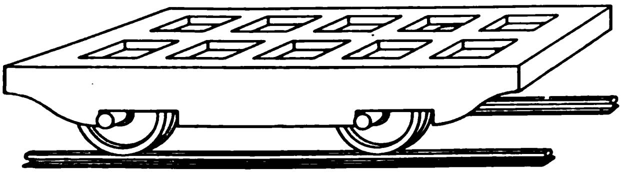


Fig. 61. Cast Iron Car.

For medium work smaller ovens of this type are used. Racks similar to the one shown in Fig. 62 may be bolted on the sides, arranged to hold the ends of the core plates; and the car may carry a line of double racks to increase the capacity of the oven.

As mentioned before, cores form those parts of a mold which will be nearly or entirely surrounded by metal. In other words, such parts as would be in danger of breaking or require too much work to construct in green sand. The object then in making cores is to make a better casting and reduce costs.

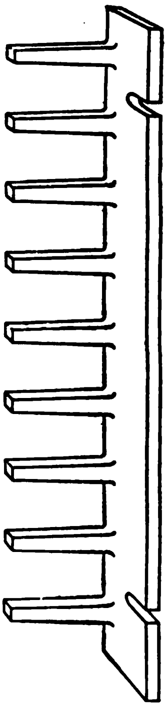


Fig. 62. Rack.

Cores are held in position by means of core prints (See Pattern Making, page 56). The main weight of the core is supported by these prints and through them all vent must be taken off and all sand removed in cleaning. Therefore cores must be stronger than green sand because whether large or small, they must stand handling while being set and must not cut or break during pouring. They require greater porosity than green sand because their vent area is limited and their composition contains more gas forming material. Furthermore, cores must lose all their bond by the time the casting is cold, so that the sand may be easily removed no matter how small the available opening.

These conditions are obtained by using a coarse free sand and a binder. To give additional strength when necessary, iron wire, or rods, or cast-iron core arbors are bedded in the core. These serve the same purpose in a core that the flask does in green sand work.

The action of the binder enables the sand to retain its shape when the box is removed, and renders the core hard and strong when baked. In the mold the intense heat of the metal gradually burns out the organic matter or "binder," leaving the core without bond. In this condition the sand may readily be removed.

Too much binder tends to make the core sag out of shape before baking, and "blow" when metal strikes it, that is, give off more gas than the vents can carry away. With too little binder the sand will not bake hard, and will "cut" when the mold is poured.

No universal mixture for core sand can be given, as sands vary so much in different localities. The following mixtures illustrate approximate proportions:

For small cores:

Beach sand	10
Flour	1

Temper with molasses water.

For large cores:

Sharp fire sand	8
Strong loamy sand	2
Flour	1½

Temper with clay wash.

For intricate smaller cores:

Beach sand	15	Beach sand	15
Fire sand	15	Molding sand	5
Rosin	2	Flour	2
Flour	1	Oil	1

Temper with molasses water.

Blacking for Light Work. One cup of molasses to a pail of water. Into this work powdered charcoal until an even black coating is deposited upon the finger when dipped into the blacking and out again.

Heavy Blacking. Use about 2 parts charcoal and 1 graphite, and mix into thick clay wash.

The effectiveness of all binders, especially flour, depends upon their thorough mixing with the sand. The especial value of rosin and oil lies in the fact that by melting under the oven heat they form a more perfect bond with the sand.

Many intricate cores are now made with an oil mixture, without using rods or wires, which formerly were considered absolutely necessary for strength.

Such cores must be well supported when green, must be thoroughly baked, and handled with much care until they are cold.

In preparing core sand the different ingredients should be measured out, thoroughly mixed and while dry, sifted. Temper the mixture a little damper than molding sand. Too much moisture will make the sand stick to the box. Not enough will make it hard to work and give a crumbly surface if dried.

In finishing small cores they should be sprayed with weak molasses water while green, then well baked and removed from the oven. When cool enough to handle, they are dipped into the blacking; then put back in the oven until this facing has dried. For large cores the blacking is applied with a brush before baking.

All cores should be baked as soon as made, for air-drying causes the surface to crumble.

Cores must not be set in a mold while they are hot, or the mold will "sweat," that is, beads of moisture will form on the inside faces. This would make the mold "blow" when poured.

A core should be rammed evenly and somewhat harder than a mold. Too hard ramming will make the sand stick in the box, besides giving trouble in casting. Too light ramming makes a weak core.

From the very nature of cores, the matter of venting them is very important and often calls for much ingenuity on the part of the core maker.

For simple straight work a good sized vent wire is run through before the box is removed. Half cores have their vents cut in each half before pasting together. Cinders are rammed in the center of large cores connecting through the prints, with the mold vents. For crooked cores, wax vents are rammed in the center—the wax melts away into the sand when the cores are baked, leaving smooth even holes. This will be illustrated in one of the following examples.

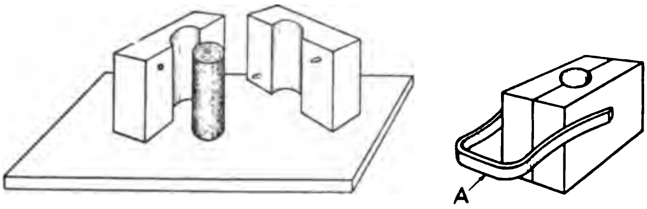


Fig. 63. Short Bolt-Hole Cores.

The examples here given will serve to illustrate the principal methods used in making cores.

The simplest form of core is one which can be rammed up and baked as made by simply removing the box. Short bolt-hole cores, etc., are made in this way, as shown in Fig. 63.

Set the box on a flat bench top. Hold the two halves together by the clamp A. Ram the hole full of core sand by use of a small rod.

Slick off the top; run a good size vent wire through the middle of the core. Remove the clamp. Set the box onto the core plate, rap the sides, and carefully draw them back from the core.

Larger cylindrical cores, up to about 1½ inches diameter, are rammed in a complete box also, only rolled out on their sides. See Fig. 64. This, however, tends to make a flat place on the side, from the weight of the sand supported on this narrow surface.

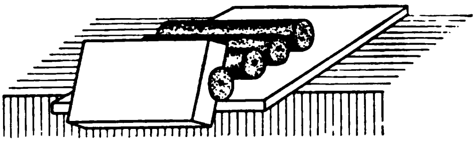


Fig. 64. Large Cylindrical Cores.

For this reason cylindrical cores of large diameter, and many symmetrical shapes, are made in half boxes. See Pattern Making, Figs. 111, 189, 194, and 200. Such boxes are rammed from the open side. Wires are bedded when necessary about in the middle of the half core. The fingers and handle of trowel are often used to ram the sand and with the blade of the trowel the sand is struck off and slicked to the level of the top of the box.

When baked, two half cores are held with their flat sides together, and any slight unevenness in the joint removed by a gentle rubbing motion. A vent channel is then scraped centrally on each half. Paste, made of flour and water, is applied around the edges and the two halves pressed firmly together; care is taken to see that they register all around. The core should then be placed in the oven to dry out the paste. When pasting cores of 6 inch diameter and over, it is well to bind the halves at each end with a single wrap of small wire.

Wherever possible, core boxes should be made with their widest opening exposed for packing the core, and designed so that the core may rest, while being baked, on the flat surface formed by striking off at this opening.

Core plates will sometimes become warped. When a core would be spoiled by resting it directly upon such a plate, the unevenness is overcome by sifting upon the plate a thin bed of molding sand and seating the core on this.

All cores cannot be made with a flat surface for baking, as illustrated by a port core, the box for which is shown in Pattern Making, Fig. 216.

This core must be rolled over on a bed of sand. Using an oil mixture, ram the core carefully, bedding into it several wax vents. These should start near the end which will touch the main cylinder core and lead out of the end which will enter the chest core. To get this crooked core on a plate for baking, a wooden frame is roughly nailed together, which is large enough to slip over the core box when the loose pieces have been drawn off of the core. See A, Fig. 65.

The space on top of the core is now filled with molding sand, rammed just enough to support the weight of the core. The edges of the frame project above the highest points of the core and form guides for striking off this sand and seating a core plate, as at B. Box, frame, and plate are now firmly clamped and rolled over, and the frame and box removed, leaving the core well bedded on the plate ready for the oven, as at C.

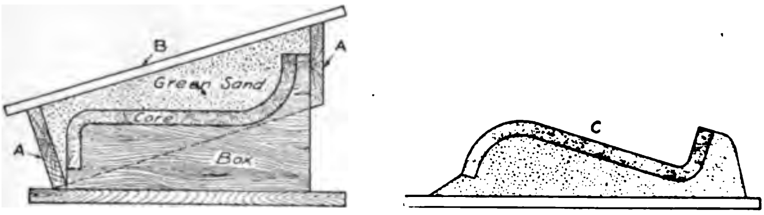


Fig. 65. Bedding a Crooked Core.

In manufacturing plants quantities of cores are often required which cannot be baked on a flat plate. To save the time and material necessary to roll each core onto a bed of sand, metal boxes are made, see Pattern Making, Figs. 227 and 228, and the core is baked in one part of the box. Only one casting is required of the larger portion of the box. The smaller part is duplicated for every core required for the day's molds.

Mention has been made of the use of wires for strengthening small cores. In making larger ones, there is a greater weight of sand to cause strain in handling the core, and proportionately greater casting strain. To resist these, a systematic network of rods is bedded in the core while being rammed, as shown in the sectional view, Fig. 66. Heavy bars *a a b b* extend the length of the core to give the main stiffness. Smaller cross rods rest on these at the bottom and top, and with the small vertical rods tie the whole core together.

At even distances from each end lifting hooks *c* are placed.

Cross rods through the lower eyes of these hooks bring all the strain of the lift on the long heavy core rods. The holes in the top of the cores where the lifting hooks are exposed, are stopped off when the core is in the mold, by moistening the sides of holes with oil and filling up with green sand.

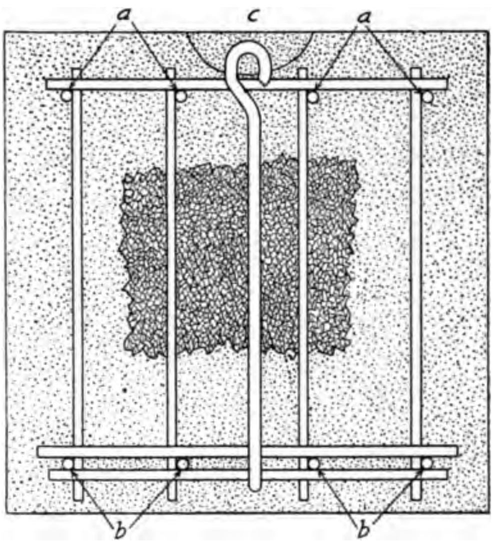


Fig. 66. Network of Rods in Core.

Cinders are packed in the middles of such cores. They aid in drying the core. They furnish good vent, and they allow the sand to give when the casting shrinks, thus relieving the strain on the metal itself.

For the largest class of cores for green sand work, cast-iron "core arbors" are used. A very satisfactory type of arbor is shown in Fig. 67. This consists of a series of light rings A carried on a cast-iron beam B. The rings are of about ½-inch metal cast in open sand and set about 8 inches on centers, and may be wedged to the beam. The beam has a hole at each end for lifting the core.

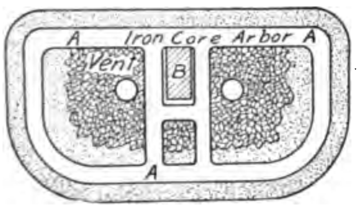


Fig. 67. Arbor.

This skeleton is made up and tried in the box before the work of ramming the core is begun. It is then removed and given a coat of thick clay wash. A layer of core sand is first lightly rammed over the inside of the box, and the core arbor seated into this. The full thickness of core sand facing is then firmly rammed, and the entire center filled with well packed cinders. Vents through the facing at both ends provide for the escape of gases from these cinders.

Often, when but one or two large cores are wanted, the cost of making a box is saved by sweeping up the core. This is illustrated in the pipe core shown in Fig. 68.

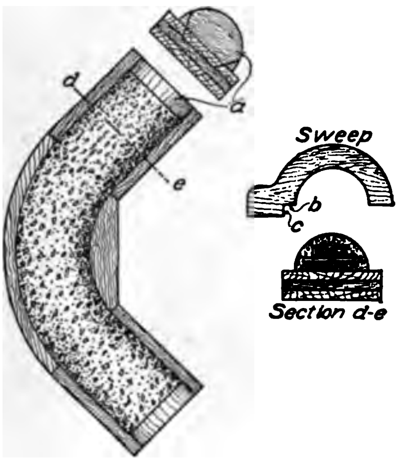


Fig. 68. Pipe Core.

The pattern maker gets out two core boards and one sweep. The boards are made by simply nailing together three thicknesses of $\frac{7}{8}$ inch stuff, with the grain of the middle piece crossing that of the others to prevent warping. The outer edges of the boards have the exact curve of the outside of the pipe pattern, and at the ends is tacked a half section of the core, shown at *a a*. One sweep does for both boards. The curve is cut the exact half section of the core The edge *b* equals the thickness of metal in the casting, and the stop *c* acts as a guide along the outer edge of the board.

In making up this core a thin layer of core sand is spread on the board and the outline of the core swept. On this the rods with their lifting hooks are bedded, and the vent cinders carefully laid along the

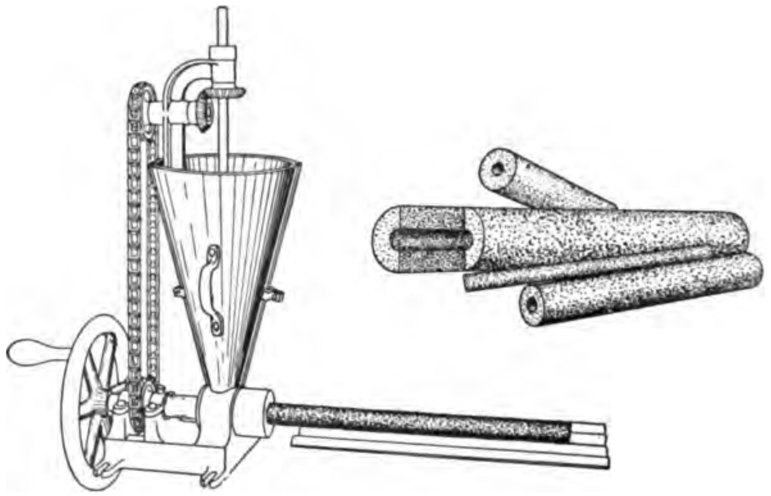


Fig. 69. Core Machine.

middle. The whole general shape is then rammed up in core sand larger than required, and by using the sweep it is brought to exact size. The core is then slicked off, blackened and baked while still on the board. When both halves are dried, they are pasted together, the same as with smaller work. To prevent breaking the lower half when turning it over to paste, it is rolled over on a pile of heap sand.

For making "stock" cores, round or square, several styles of core machines have been put on the market within the last few years, of which the accompanying cut, Fig. 69, is a good representative. This is arranged to be driven by hand or by power. The core sand is placed in the hopper and by means of a horizontal worm at the bottom, it is forced through a nozzle under just the right pressure to pack the core firmly. A clean cut vent hole is left in the middle of each core. As the core is forced from the nozzle it is received on a corrugated sheet steel plate, which is moved along to the next groove when the core has run to the full length of the plate.

The advantage of the machine is that with it an apprentice boy can produce a true, smooth, perfectly vented core, in very much less time than could possibly be done by hand ramming.

SETTING CORES

The following examples show typical ways of setting and securing cores in molds and of connecting vents.

A bolt hole core, shown at A, Fig. 70, illustrates the simplest form of core to set. Only a drag print is necessary; the flat top of the core should just touch the cope surface of the mold. The level may be tested by a straight stick or by sighting across the joint. If the core is too long, one end may be filed off a little; if too short, a little sand may be filled into the bottom of the print. For longer cores, especially

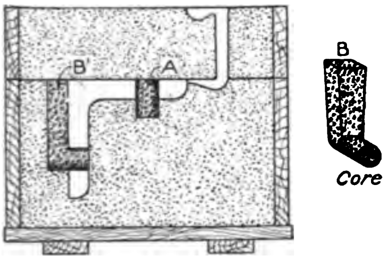


Fig. 70. Bolt-Hole Core.

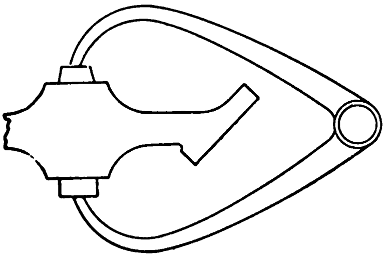


Fig. 71. Callipers.

hub cores, a taper print is placed on the cope side of the pattern, and the same taper is given to the end of the core; this guides it to the exact center when the mold is closed. Numerous examples are shown in Pattern Making, pages 103 to 107. The exact length of the core should be obtained from the pattern with a pair of calipers, as shown in Fig. 71. One point of the calipers should then be placed on the taper end of the core, and the print filled in or the core shortened in case of variation from the right length.

It is well to make a vent hole from the center of each print before setting the core.

With pattern and core boxes properly made, little difficulty should be experienced in setting small horizontal cores for hollow bushings, pipe connections, etc. (See Pattern Making, Figs. 111, 186 and 191.) The core must fit the print or a poor casting will result. The sand supporting the prints must be tucked firmly enough to withstand the lifting pressure on the core. A scratch with the point of the trowel along the joint surface from the end of the print to the edge of the flask, will usually take care of the vent.

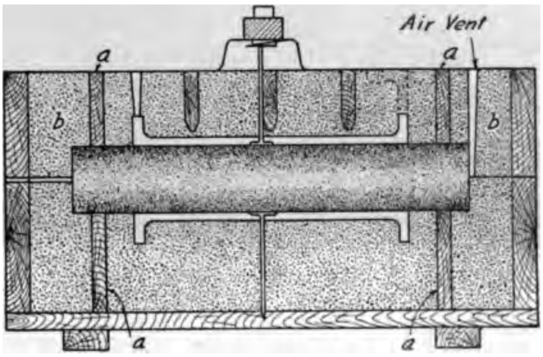


Fig. 72. Body Core, Supported.

For larger cores of this character, crossbars are nailed in both drag and cope made to fit snug against the core print. See *a a a a*, Fig. 72. These hold the core absolutely firm. The spaces *b b* in the cope, are not packed until the core is set, when it is a simple matter to ram these spaces and take off an air vent directly from the center of the core.

In setting chaplets, the height of the lower one may be tested with a rule, with a straight edge rested on the prints, or by a guage similar to that shown in Fig. 73. A small boss is usually formed by pressing the trowel handle into the mold where the chaplet is to go.

The cope chaplet is not fastened until the mold is closed, then the stem can be properly wedged down under a bar clamped across the top of the mold.

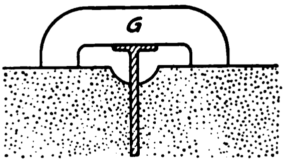


Fig. 73.

There are two methods of coring holes below the level of the joint. One is shown clearly in Fig. 74. A "stock" core is set in the bottom of the prints; a wooden template, shown at *b* and *b′*, is set over the core, and the print *a* is then packed with molding sand or "stopped off," as it is termed.

The other method is shown at B and B′, Fig. 70. Here that part of the core which will shape the hole through the casting, is formed on the end of a core which exactly fills the print. A single operation sets the core and stops off the print. For this reason this method is used where a large number of such holes are to be cored.

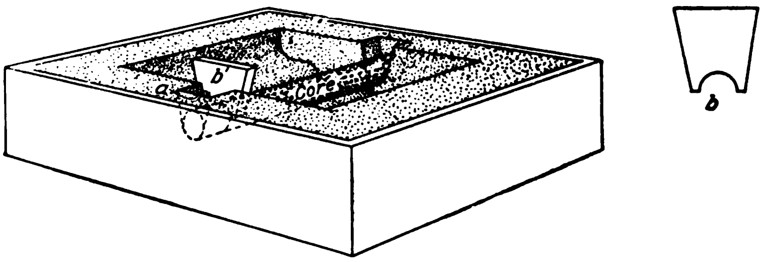


Fig. 74. Setting Core Below Surface.

In work where a hole must project well into the casting but not all the way through it, a balanced core is often used. Such a case is illustrated by the rammer head, Fig. 75. When making this core, let the vent extend through the entire length, then stop up the vent at the small end with a bit of clay after the core is baked.

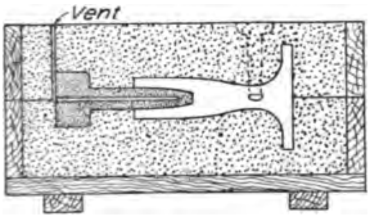


Fig. 75. Small Balanced Core.

It is not always practicable to enlarge the print as shown here, but when possible, it reduces the length of print necessary to balance the projecting end and ensures accurate depth to the hole.

Heavy projecting cores must be supported by chaplets, as illustrated in Fig. 76. Vents may be taken off through a channel and air riser as explained in the section on venting. Fig. 77 shows the shape of the print on the pattern for this mold at *a*, the pockets formed by the core are shown at *b b*, and *c* indicates the position of the gate.

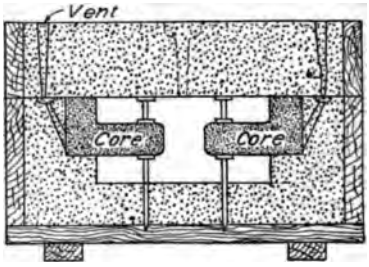


Fig. 76. Large Balanced Core.

A core is frequently used to avoid a deep lift for the cope. Suitable wire hangers, shown at *a*, Fig. 78, are bedded in the core when it is made. In setting the core small annealed wire about No. 20 or No. 24 gauge, is looped through the hangers, passed through small holes made in the cope, and fastened with a granny twist over an iron bar on top. This bar should bear on the sides of the cope and the core be brought up snug in its print by wedging under its ends. The "rigging" need only be strong enough to support the weight of the core, for the pressure of metal will force this core firmly into its print with little danger of shifting it. For heavy cores a lifting eye, as previously illustrated in Fig. 66, takes the place of the wire hanger, and the core is hung by means of a hooked rod with a nut on the end. As shown in Fig. 79, this rod passes through a long washer which bears on a pair of rails, or similar stiff rigging.

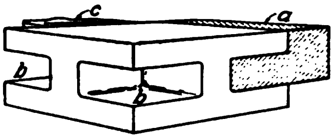


Fig. 77.

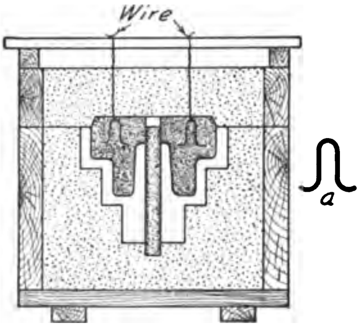
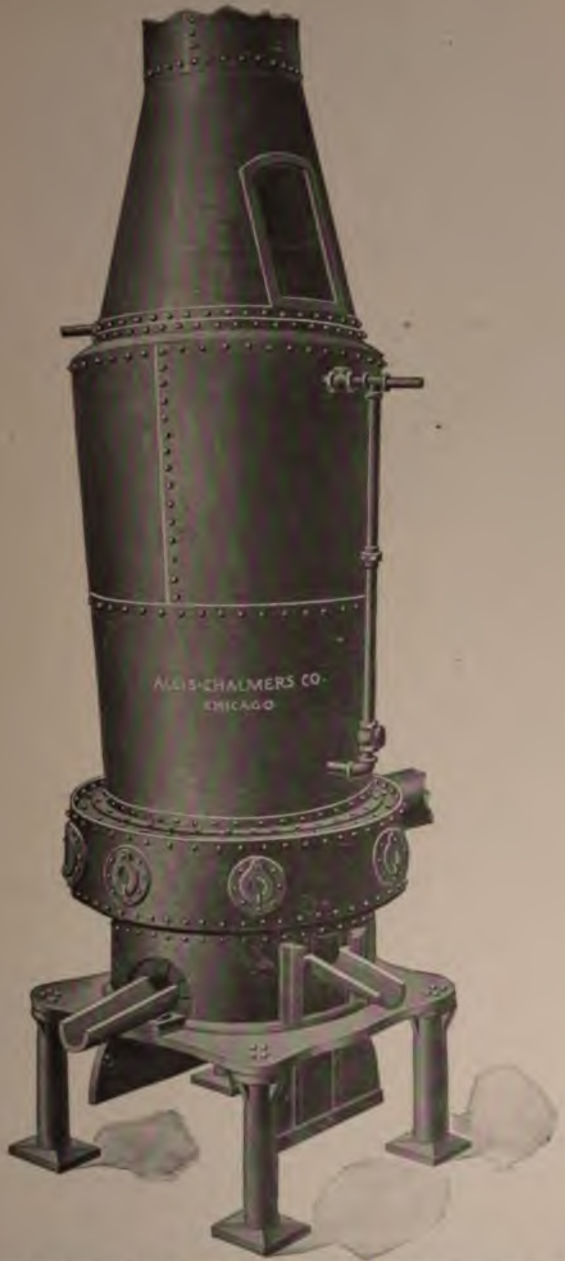


Fig. 78.

Where possible, the placing of cores in the bottom of molds should be avoided, for in this position, being much lighter than molten iron, they must be secured against a pressure tending to float or lift them.



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This pressure is proportionate to their depth below the pouring basin. But the metal at the bottom of a mold is cleaner and more sound than that at the top. Therefore, planer beds, large face plates and pieces of this character, are usually cast face downward, making it necessary to anchor the T-slot cores in the bottom of the mold.

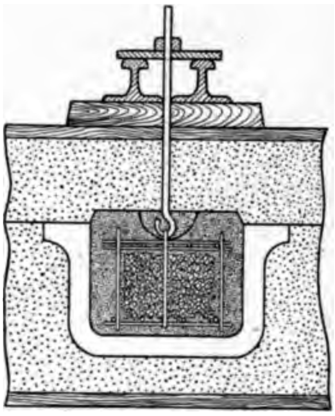


Fig. 79.

In some cases such cores may be held down by driving nails so that their heads project somewhat over the ends of the core, as shown in Fig. 80. If this method is not strong enough, pointed anchors, with a foot on one end, are run through a hole in the core, and are carefully driven into the bottom board. See Fig. 81. Where the work is bedded into the floor a plank must be set to receive these anchors just below the cinder bed. As in the case of lifting eyes, the holes in the core, into which the foot on the anchor is driven, are smeared with oil and stopped off with green sand.

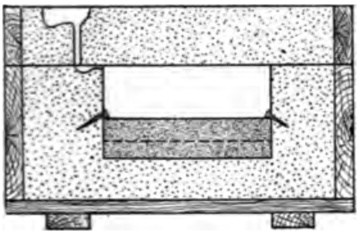


Fig. 80.

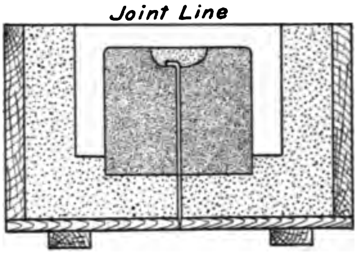


Fig. 81.

DUPLICATING CASTINGS

Devising methods for increasing production and decreasing its cost is one of the important problems of modern engineering in the foundry as well as elsewhere. In the jobbing foundry where there is a great variety, not only in the patterns themselves, but in the number of castings called for from each pattern, the molder makes up a sand match as already described.

On this match he arranges such an assortment of patterns as will fill his flask and beds them into place. From a well-made sand match two or three hundred molds may be made up. When the desired number of castings is made from one pattern on the match, that one is removed and another one which will fit in its place is substituted.

For manufacturing purposes thousands of the same casting may be required calling for more durable patterns and match. Metal patterns are made and as many as can be cast in a flask are soldered to a smoothly finished metal gate pattern. With a draw screw inserted in this gate, all of the patterns may be drawn at once. Two steady-pins should be screwed and sweated into the drag side of the gate pattern. These should be of small round brass rod and project below the deepest point of the patterns. They guide the pattern as it is being drawn and prevent it from swaying and breaking the edges just as it leaves the sand. Patterns so arranged are termed "gated patterns."

When such patterns have a flat joint, a special mold board should be provided and the patterns stored on the same board. When the joint is irregular, a permanent oil match should be made. Make a strong hardwood frame the size of the flask and about 1 inch deep, with the bottom board arranged to screw on to the back. Nails should be driven into the inner sides hanging parallel to the bottom board. Measure the quantity of sand needed to fill this match. Mix thoroughly and put through a fine sieve, while dry, one-half this quantity of burnt sand, one-half new molding sand, and about one-fortieth litharge. Temper the same as molding sand, using boiled linseed oil. Ram up drag and joint the mold very carefully. Put on the match frame and ram up with the above mixture; strike off, and screw on bottom board. Remove drag and allow the match to dry for a day with the patterns left in it. A coat of shellac when dry will improve the surface. Fig. 82 shows a set of gated patterns bedded in a hard match.

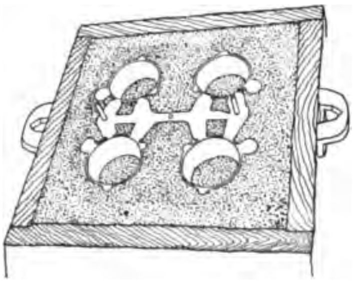


Fig. 82. Oil Match.

MOLDING MACHINES

Although there are many styles of molding machines on the market, there are practically but three separate types: Those designed to simply draw the pattern; those which only ram the flask; and those where the mechanism is arranged to perform both of these operations.

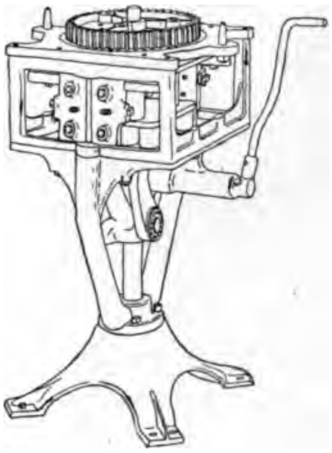


Fig. 83. Molding Machine.

Machines are used to make it possible to turn out larger quantities of small work or to simplify the production of difficult castings. The kind of machine used will vary according to the line of casting to be made. Iron flasks are used with these machines for medium weight casting, while for light work the snap flask is almost universally employed.

In Fig. 83 is shown a molding machine of the first type spoken of above. The pedestal base of the machine has a flat top. The stripping plate is supported above this by a rigid open framework. Working in guides carried on the sides of this framework is the drawing frame made to raise or lower by a strong crank and connecting rod. On top of this drawing frame and parallel to the stripping plate is

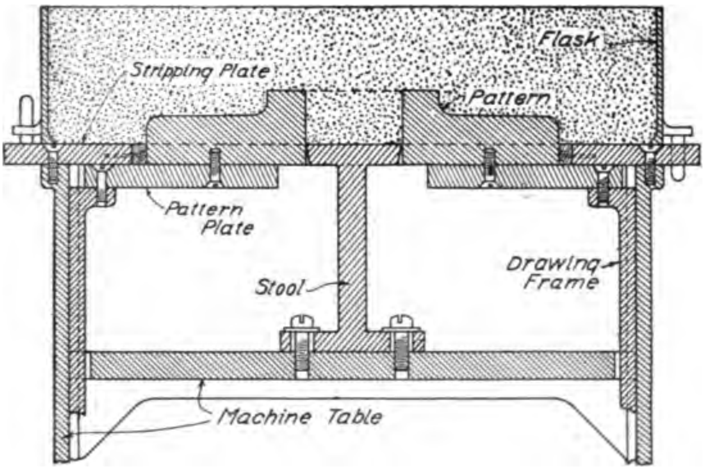


Fig. 84.

screwed the plate to which the pattern is fastened. The stripping plate is cast with an opening which leaves about 1 inch clear all around the pattern. When both pattern and stripping plate are properly set in place, this space is filled with babbitt metal; this being an easy way to secure a nice fit.

In many cases there will be an interior body of sand to be supported when the pattern is drawn. To accomplish this *stools* are used. A leg screwed into the stool plate supports the stool at the exact level of the stripping plate. The *stool plate* is fastened to the flat top of the machine inside of the box-like framework which supports the stripping plate. See Fig. 84.

The gear wheel mounted in Fig. 83, would be a difficult pattern to duplicate by simple hand drawing; the machine insures a perfectly clean draw. A box is inverted on the machine, rammed, vented and struck off. A movement of the crank lever at the side draws the pattern. The mold is removed and set on a level sand floor, thus doing away with bottom boards. A second stripping plate and pattern is used for ramming the cope boxes.

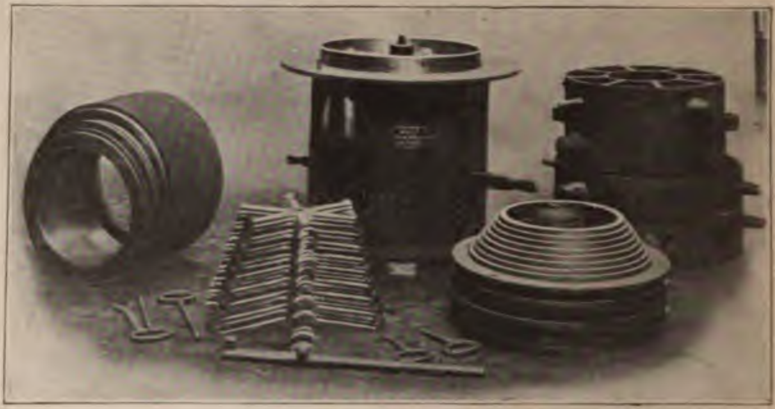


Fig. 85. Pulley Molding Machine.

Pulleys are manufactured on molding machines of this type, as shown by the equipment illustrated in Fig. 85. The rim patterns have the form of long hollow cylinders and can readily be set for any desired width of face. The hub carrying the core print separates from the spokes, lifts off in the mold and is drawn by hand. The arm patterns are so flat and smoothly rounded that the mold is easily lifted off of them with little fear of breaking the sand. Cope and drag molds are both alike for a pulley mold.

Fig. 86 shows a type of machine which only packs the sand. Here the *patterns* are carried on *two sides of a plate* set between the cope and drag. Both boxes are filled with sifted sand and set on the machine. The boards are made to slide inside of the flask. The molder's weight on the lever compresses the sand.

The sprue is cut by a thin hollow steel tube called a *sprue-cutter,* which is pressed through the cope sand by the molder before separating the flask. In separating the mold the cope is first lifted from the drag and the plate is gently rapped and lifted from the drag. To make a clean lift when parts of the patterns project in the cope, a second molder raps with an iron bar between the battens of the bottom board while the cope is being drawn off.

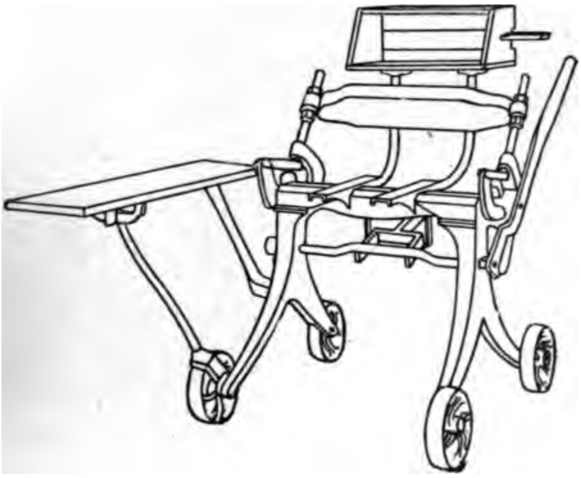


Fig. 86. Molding Machine, or Squeezer.

Such machines are used chiefly on thin work which will vent and solidify very rapidly—for the outer surfaces of the drag and cope are apt to be rammed so hard that they might choke the vent on heavier castings.

Fig. 87 shows the operation of the lever mechanism by which one movement draws the presser head over into place and then pulls it down to compress the sand.

With the third class of machine both hand and power are employed for the operating. A hand machine, built on the same lines as the previous example, is shown in Fig. 88. With this machine *gated patterns* are mounted on a *wooden board or hard match.* Snap flasks are used and when the size of the work will permit, both cope and drag parts are set up side by side on the same machine.

The amount of sand to be compressed is regulated by the depth of the *sand frame* which is set on top of the boxes. To avoid ramming the higher portions of the pattern too hard a thick block is fastened to the *presser head.* This block is hollowed out to conform with the shape of the patterns, as shown in the small cut. This excess is struck off before the patterns are drawn. A movement of the lift lever raises the lift table. This in turn raises four pins which pass through the corners of the pattern board, engage the edges of the flask and lift it perfectly straight off of the patterns. The end of a rapping bar may be seen under the pattern board of the cope box. With this the board is rapped while the lift is being made.

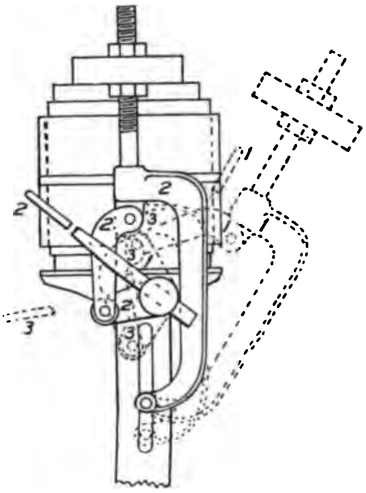


Fig. 87. Lever Mechanism.

Compressed air, steam, and in some styles, power transmitted by belting, are used for operating many molding machines. Compressed air is, however, more frequently met with. Fig. 89 shows a modern machine. The sizes range from 14 x 20 inches to 40 x 90 inches.

In operation the facing sand is tucked by hand, and the flask and sand frame filled. The presser head is swung forward but remains stationary, and the whole machine table, bearing patterns and flask are forced upward against it, by means of a cylinder underneath the center of the machine. Two or three blows are given as if by a steam hammer.

Either a stripping plate, pattern board, or pattern plate is used. As a substitute for rapping the patterns a small pair of cylinders is attached to the frame which carries them. These cylinders contain a small piston which is driven back and forth very rapidly, giving a trembling motion to the patterns. This attachment is called a pneumatic vibrator.

A rubber tube with a nozzle is conveniently attached to the compressed air pipe and provides a ready means for the molder to blow his mold clean. The force of this air is regulated by a spring valve attached to the nozzle.

On the large machines all operations, even to the swinging of the presser head, are accomplished by compressed air, controlled by a few conveniently placed levers.

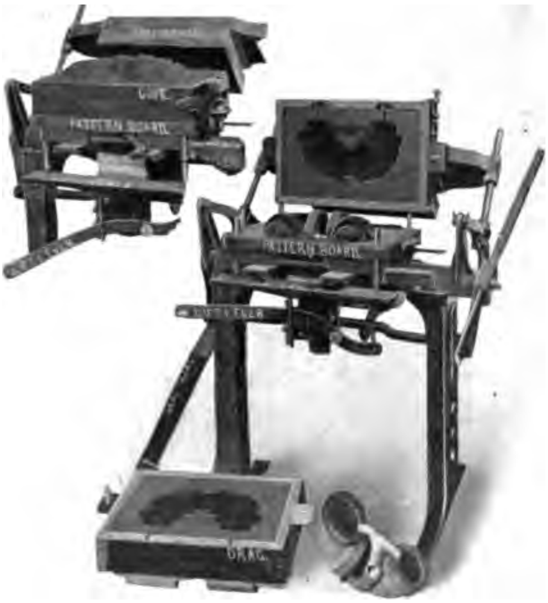


Fig. 88. Squeezer, with Device for Drawing Patterns.

The advantage of molding machines lies in the fact that they can be operated with practically unskilled labor, because there is no skill required in drawing the pattern, in repairing the mold, or in gating, and in many, none required in packing the flask. All of these are points which ordinarily call for sound judgment and a high degree of skill on the part of the molder. The limitation of the simple squeezer due to hard surface ramming, has been mentioned.

The tendency of molding machine practice in the jobbing shops is toward a hand-rammed, stripping-plate machine, because the jobs may be changed quickly and the more intricate patterns can be rammed just right. The great expense of metal patterns and stripping plate is being overcome by the use of ordinary wooden patterns and a stripping plate made of well-seasoned oak, which has been boiled in paraffin to prevent it from warping.

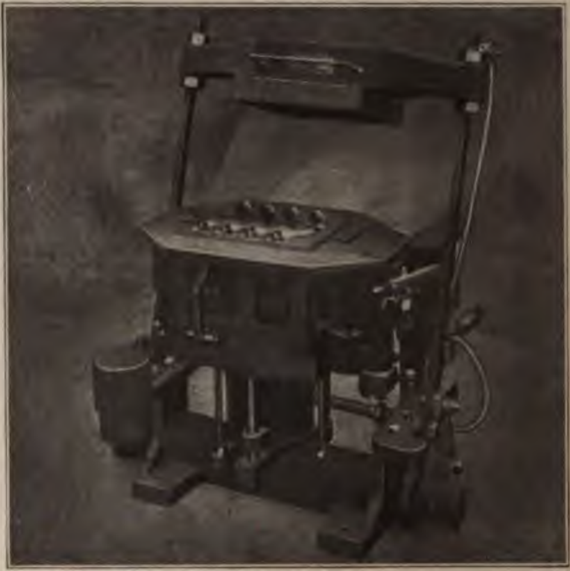


Fig. 89. Molding Machine. (Rams by Power and Draws Patterns Automatically.)

DRY SAND WORK

This branch of molding becomes a separate trade in shops where the work is done continually. The dry sand molder must use the same precautions as the green sand molder in setting gates, risers, and fastening his sand with crossbars and gagers. At the same time he works with a core sand mixture next his patterns and backs this with a coarse molding sand. So that he must combine the skill and judgment of both green sand molder and core maker. The venting of dry sand work must be ample as in the case of cores, but it is simpler than in core work, because the core mixture surrounds the casting so that vents may be taken off in all directions.

Iron flasks are used, generally provided with trunnions to facilitate turning. The facing mixture is the same as that used for making large cores. See Core Making. The remainder of the flask is packed with the same sand after it has been used. The patterns are made and used the same as with green sand, only they should be brushed over with linseed, crude-oil or other heavy oil before ramming. In some shops oil is brushed over the joint before parting sand is thrown on. After the pattern is drawn, the mold is finished by applying a heavy coat of good black wash. When the sand has absorbed the moisture so that all glisten has disappeared, this blacking is slicked over. Great care must be exercised in this operation, for too much slicking will draw the moisture to the surface again and result in scabs on the casting.

Engine cylinders are a representative line of work for dry sand. Consider the simple type of cylinder shown in Pattern Making, page 115, to have a bore of from 16 to 26 inches with the exhaust-outlet flange placed above the center of the cylinder. To facilitate setting the cores the pattern will be split through the steam chest. The flange just mentioned will be molded in the drag; it should be made loose and draw in the opposite direction from the main pattern. The cylinder core will be made on a "barrel" (explained later on page 67) and the mold poured on end to insure sound metal and to reduce the casting strain on the port cores. The flask is made with a round opening in one end to allow the core to project through it. This opening is larger than the diameter of the core to allow for gates and risers. There must be another opening at the side of the flask opposite the

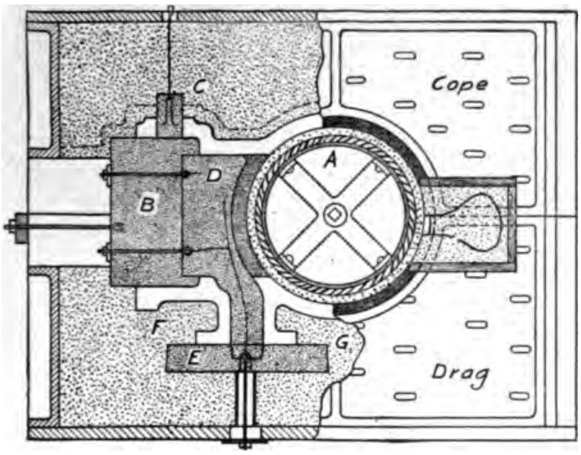


Fig. 90. Molding a Cylinder.

steam chest core to provide for fastening these cores. Iron plates serve for flask boards and there should be a hole in the drag plate opposite the exhaust core to allow for venting and fastening its end.

One half of Fig. 90 shows the end view of the flask. The other half shows a section through the middle of the completed mold. Here A is the hollow cylinder core, B is the chest core, C the live steam core hung in the cope, D the exhaust core. The flask is packed in a manner similar to green sand. The method of molding the exhaust flange, however, has not previously been explained. To do this, proceed packing the drag until the pattern is covered. Tuck the facing carefully underneath the flange, setting in rods as in core work, to strengthen the overhanging portions. Make a flat joint, F G, at the level of the top of the flange, then carefully fit over the print of the flange the cover core, E, and fix its position with nails driven into the joint at its corners. Now remove the cover core, draw the flange and finish that part of the mold with black wash and slicking. When this is accom-

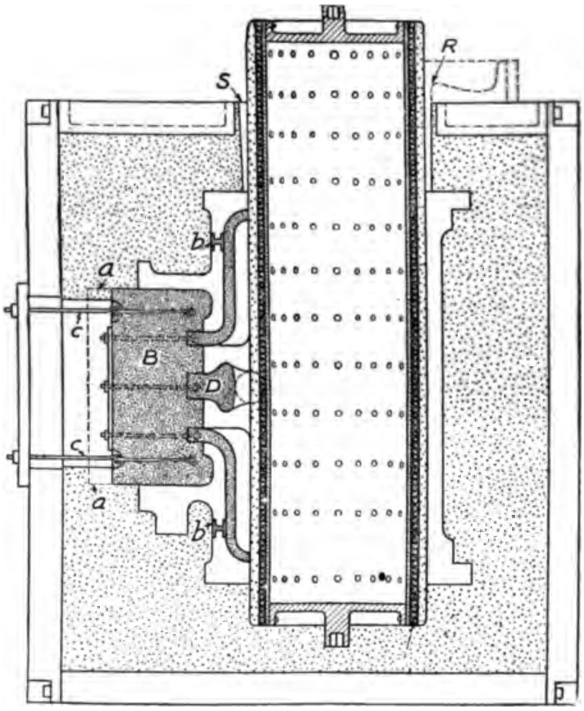


Fig. 91. Plan on Drag.

plished, replace the cover core, place a short piece of pipe over its central vent, and finish ramming the drag. This method may be used in many cases, both in dry sand and green sand work where a small detail of the casting requires a separate joint surface.

A sectional plan looking down on the drag is shown in Fig. 91. When the mold has been properly finished and baked, the drag is brought from the oven and set on a pair of stout horses. The cylinder core is first set in place, then the exhaust core is set in its drag print and held close to the cylinder core, while the port and chest cores, previously pasted and fastened, are lowered into the chest print. The chest print is cut a little long at *a a*, to allow its core to be drawn back slightly while the exhaust core is entered into its place between the port cores. Then all of the cores are set forward into position, the chaplets *b b* set, the space *a a* tightly packed again, and the anchor bolts *c c* placed in position and made fast. The drag print of the exhaust core is made fast from underneath the drag plate. When all the cores have been firmly fastened, the cope is closed on, the two boxes clamped at the flanges, and set up on end. The runner R and the riser S were cut and finished before baking; the basins must be built in green sand after the mold is closed.

MAKING A BARREL CORE

Loam is used here for the outer shell of the core. It is probably the simplest job in which a loam mixture is employed, and is made by a core maker more frequently than by the higher paid loam molder. Barrel cores are used where the core is long and can best be supported at the ends only; for example, in gas and water pipes and cylinder work.

Loam is a facing mixture, of the consistency of mortar, applied to the face of the core or mold. It contains fire sand with a bond of strong porous molding sand moistened with a thick clay wash. A small proportion of organic matter in the shape of horse manure is put in to aid the bond and to leave the crust of loam more fragile by burning out as the casting cools. Proportions of the mixture will vary according to locality, but the principles already cited hold here as with other molding compounds. With too much bond the loam works easier but tends to choke the vents when casting. With not enough it will be weak and liable to break, cut or crumble under strain. A typical mixture is as follows:

	Mixed by Hand	Mixed by Mill
Fire sand	10 parts	10 parts
Strong coarse molding sand	4 "	3 "
Horse manure	1½ "	2 "

Wet with thick clay wash.

The advantages of loam cores are that they are lighter, cheaper to make, and carry off the gases faster than do dry sand cores.

The method of making barrel cores is as follows: A piece of pipe about three inches smaller than the outside diameter of the core is selected to form the center. The pipe is perforated with a large number of holes. If the pipe is more than three or four inches in diameter, centers or trunnions are riveted in the ends to serve as bearings. The pipe is arranged to revolve freely on a pair of iron horses, as shown in Fig. 92. A crank handle is attached by which the pipe may be turned. A couple of wraps of hay rope are first given around one end of the pipe and the loose end pinned flat by a nail run under these strands. Tight wrapping is then continued to the other end of the pipe where the rope is fastened in a similar manner and cut off. Hay rope should be made of long wisps tightly twisted. Sizes vary from ¾ to 1 inch. Where only a small amount of hay rope is used, it is bought ready made. Foundries using large quantities are equipped with one or more machines built especially for making this rope.

The first coat of loam is rubbed on with the hands, then well pressed in with the flat side of a board as the barrel is slowly revolved. When this has set, the core board, A, is placed in position, and the roughing coat worked on to the core to within about ¼ inch of finished size. The core is now dried in the oven. Placing the core again on the standards, the finishing coat of "slip" is applied with the core board while the core is still hot. The diameter is tested with calipers and brought to required size by slight adjustment of sweep board A. When the core has been built to size, move the loam back from the edge of board A, then withdraw the board while the "barrel" is still in motion.

Slip or *skinning loam* is made by thinning regular loam as it is rubbed through a No. 8 sieve. The heat of the core is usually sufficient to dry this slip coat enough so that black wash may be brushed on and slicked, as in dry sand work, before running the core into the oven again for its final baking.

The service of the hay rope on a barrel core is twofold. It furnishes a surface over the smooth metal of the barrel to which loam will adhere; and it is elastic enough to give as the casting shrinks around the core. The hay slowly burns out after the casting has set, and this frees the barrel so that it can easily be withdrawn and used again.

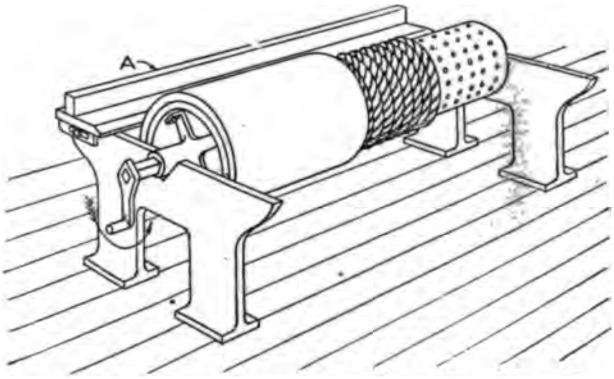
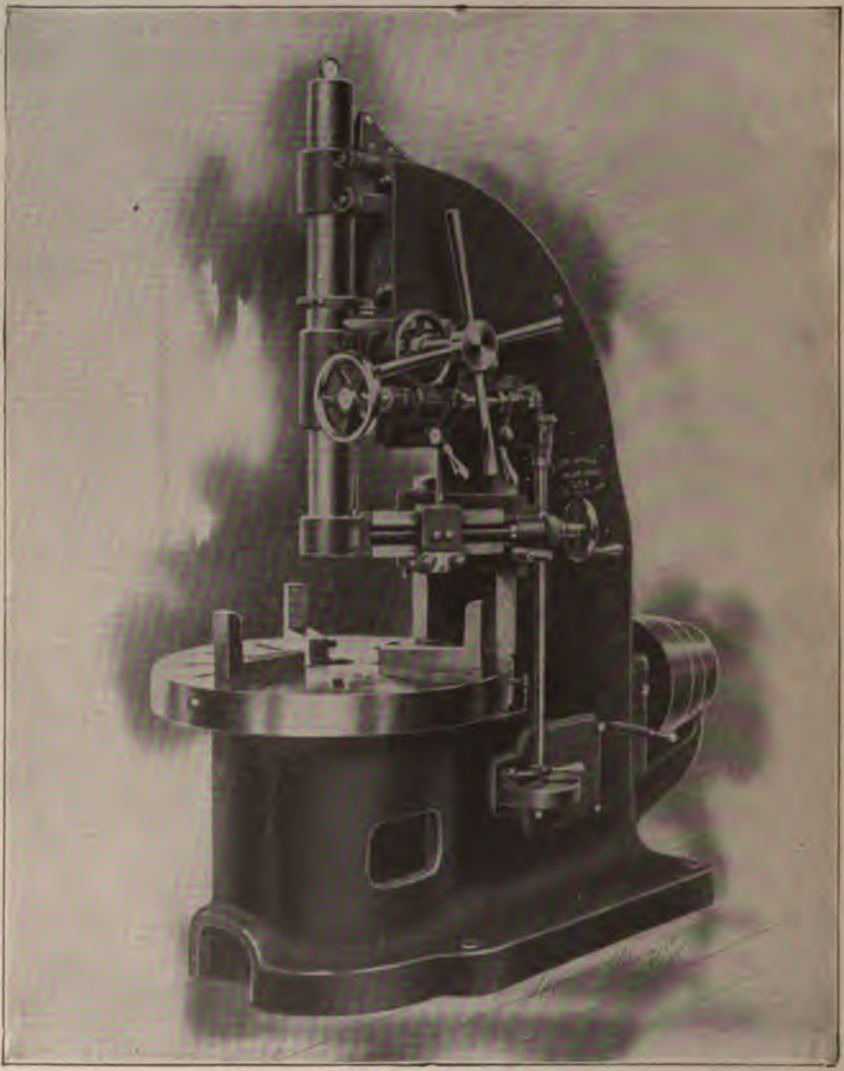


Fig. 92. Making Loam Core for Cylinder.



CAR-WHEEL BORER.
Baker Brothers.

FOUNDRY WORK

PART II

LOAM MOLDING

The loam molder requires the greatest all-around skill in the whole range of foundry work. He must know all the tricks of core room and dry sand shop, and most of those in green sand. Added to all this he must have a practical working knowledge of the principles of drawing and must possess to a large degree the foresight of the designer.

In order to save time and lumber in the pattern shop, only a set of sweeps are provided if the mold is simple, and these with blue prints of the piece wanted, is all the molder has to work from. In intricate work, such as a modern Corliss cylinder, a skeleton pattern carrying the steam chests, etc., in accurate position is made. And in some very crooked work a pattern is furnished complete. As a rule, however, the loam molder must rely upon his own skill and ingenuity for the best method of constructing each detail of the work.

Rigging. The equipment for the loam floor varies in different shops. In Fig. 93 is shown the essential features of an equipment for sweeping up circular forms.

The **spindle** *a* should be large enough not to spring when being used, and long enough to conveniently clear the highest mold. A piece of 2-inch shafting is a handy size, for with it the sweeps may be made uniformly 1 inch less than the required diameter and placed snug to the spindle when set up and correct size of mold is ensured. This spindle should revolve smoothly in a *step b*. The step shown may be set at any convenient place on the floor. It has a long taper bearing, (see section A), capable of holding a five-foot spindle without need of any top bearing for same. The three arms serve to make the step set firm, and upon them any plate may be readily leveled up. Where a tall spindle is used the spindle socket will be more shallow, the step may be cast without arms and be bedded in the floor. The top of the spindle is steadied by the *bracket c*. This must carry a bearing *box* so designed that the spindle may be readily set in position or removed. And the bracket must swing back out of the way when any parts of the mold are to be handled by the crane.

The sweeps are attached by means of the *sweep arm d.* The detail B shows one method of clamping sweep arm to spindle by using a key. The arm is offset so that one face hangs in line with the center of the spindle. Bolting the face side of the sweep to this brings the working edge in a true radial plane. *Sweeps* are usually made from pine about $1\frac{1}{8}$ inches thick. The working edge is cut to the exact contour of the form to be swept, and then beveled so that the edge actually sweeping the surface is only about $\frac{3}{8}$ inch. For very accurate work or when sweeps are to be much used, the edge is faced with thin strap iron to prevent wear.

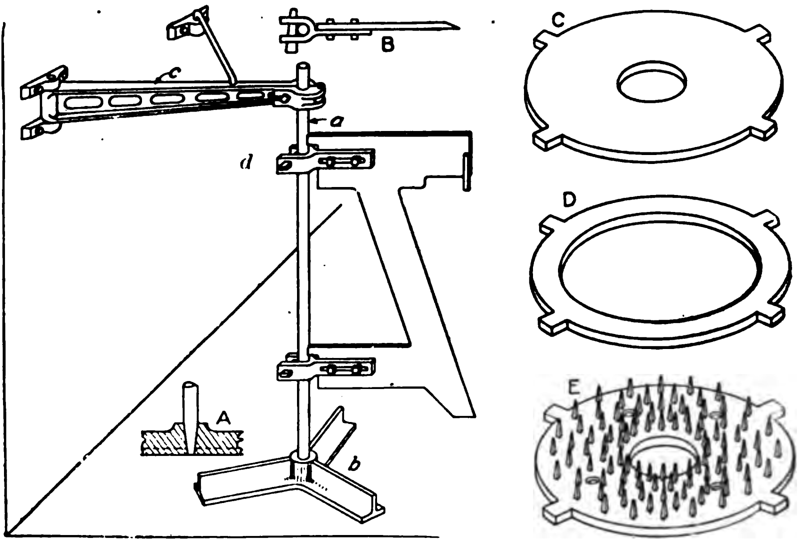


Fig. 93. Rig for Loam Work.

We have seen that the walls of green and dry sand molds are supported by sand packed into flasks and that these flasks may be lifted, turned up sideways or rolled completely over to suit the convenience of the workman. The facing which forms the wall of a loam mold is supported by brickwork built upon flat *plates* of cast iron, and laid in a weak mortar of "mud." From the nature of their construction, therefore, these molds must always be kept perpendicular when being

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handled. The parts may be raised, lowered, or moved in any direction horizontally, but they must not be tipped or rolled over.

The plates are cast in open sand molds, as illustrated in Fig. 56. Two methods are employed to provide for handling them by the crane; either *lugs* are cast on the edges of the plates (see Fig. 93, C, D, and E), or wrought *staples* are cast in the plates, as shown in the example B, Fig. 94, or in the crown plate of the main cylinder core, Fig. 97.

Three typical plates for a loam job are shown in Fig. 93. C is the *building plate;* it should be at least 18 or 20 inches larger than the

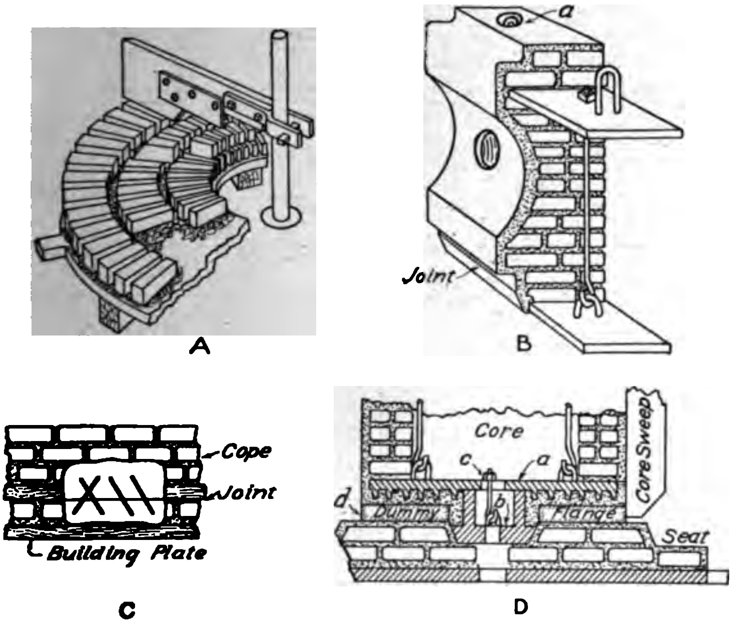


Fig. 94. Laying up Loam Work.

largest diameter of the casting to be made, and thick enough to support the weight of the entire mold without springing. D shows a *"cope ring;"* its inside diameter should clear the casting 2 inches on all sides. The face should be 8 to 12 inches wide, depending upon the height of the mold. E shows a *cover plate;* its diameter will equal the outside diameter of brickwork on that part of the mold which it will cover. Here the loam facing is placed directly on the iron, and must be supported when the plate stands vertically or is turned completely over (C, Fig. 96). To hold the loam in this way, *"fingers"* or *"stickers"* are cast on these plates. This is accomplished by simply printing the end of a tapered stick into the bed of the open mold which shapes the plates. These "sticker plates" are often used for a purpose similar to core E, Fig. 90, and shape the outer face of a picked-out flange. This is illustrated in D, Fig. 96.

Materials. Common *red bricks* are best for making loam molds. They should be free from glaze and have a uniform texture, so that they will break clean when it is necessary to fit them to the shape. An old 12-inch half-round file makes a handy tool for cutting these bricks. Sometimes bricks are molded up from loam, and air-dried. These are much more fragile than red bricks, and may be used in pockets, or where the shell of the casting is quite thin, and ordinary brick might resist the shrinkage strain to such an extent as to endanger cracking the casting.

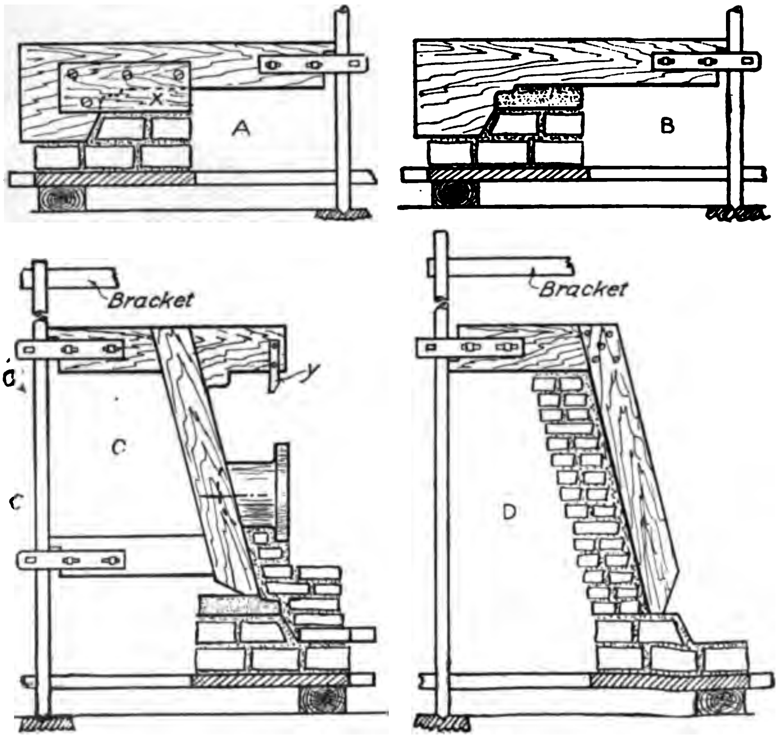


Fig. 95. Steps in Sweeping up Type Mold.

For laying up the brickwork, "*mud*" is used, loam facing being applied only to those surfaces which come in actual contact with the iron. Mud is made from burnt loam or old floor sand, mixed with clay wash to the consistency of mortar.

The composition of loam facing and "slip" have already been given under head of Making a Barrel Core.

Cinders are an important material in this work. Their size will depend upon their position in the mold. For working in between the bricks they should be crushed if necessary; put through a No. 4 sieve to remove smallest pieces, then passed through a No. 2 sieve to remove the larger pieces.

Principles of the Work. The names of the main parts of a loam mold differ somewhat from those applied when molding in flasks. As will be seen from the section, Fig. 96, there are three main divisions in the mold: A, which corresponds to the drag in a three-part mold is called the "*core.*" B, which corresponds to the check is called the "*cope*" in loam work. And C, which serves the same purpose as the cope of a green sand mold, is spoken of as the "*cover*" in loam molding. When the central core is actually made a separate piece as in Fig. 97, the lower part of the mold is called the "*bed*" or "*foundation.*"

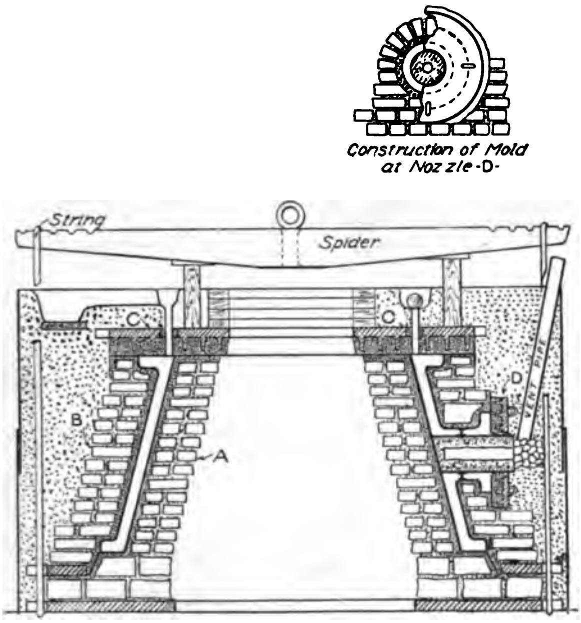


Fig. 96. Complete Typical Loam Mold.

In *laying up* a loam mold, set the plate central with the spindle and approximately level. Then set the sweep and finish leveling the plate until repeated measurements at the four quarters of the circle show a uniform space between the lower edge of the sweep and the surface of the plate. For the building plate this measurement should be 5 inches; for a sticker plate the sweep should clear the sticker points by ½ to 1 inch according to the thickness of the casting.

The *hands* are used in *spreading* mud or loam upon the plates or brickwork when building the mold. The bricks must always be set well apart, leaving a space at least the width of a finger between them. *Fill* in these *spaces* with fine *cinders*. The reason for this is fourfold. It facilitates *drying;* it provides good *vent;* it will *give* or *crush* sufficiently when the casting shrinks not to cause undue strain; and it *reduces* the *labor* in cleaning. In each course of bricks the joints should lead as directly as possible away from the casting, but the joints should be broken between courses. These points are illustrated in the sketch A, Fig. 94. As shown, the first two courses of the core are usually set edgewise. For the rest of the core and for the cope, the bricks are laid flat. These bricks run lengthwise around the circumference, with a course of "headers" about every four to six courses.

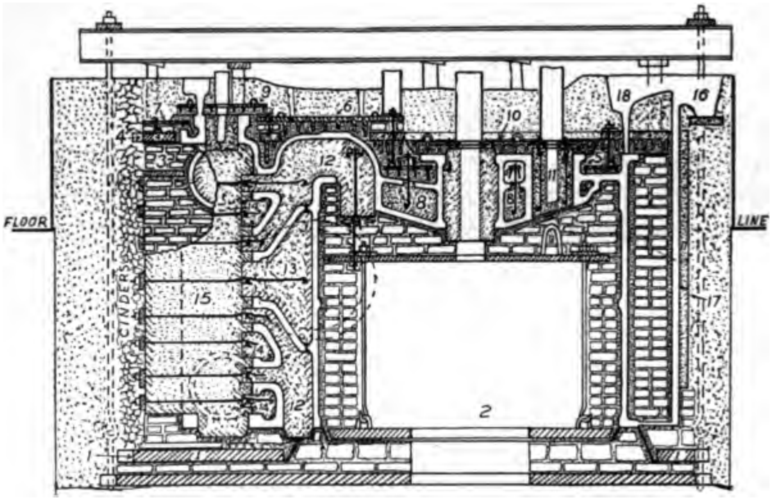


Fig. 97. Loam Mold for Marine Cylinder.

Cinders between the bricks form the ordinary means of leading the vent from the loam facing. In confined places or "pockets," as for example, between the flange D and the main casting, Fig. 96, additional provision is made by laying long wisps of straw between the courses of bricks. The service of the straw is similar to the hay rope of a barrel core.

The *joint* in loam work is made by a plate lifting away from a loam seat or two loam surfaces separating one from another. In forming the first of these the loam seat is swept up and allowed to partially set, then the surface is brushed with oil, and parting sand thrown over it. The seat should then be soft enough to allow the iron plate to sink into it sufficiently to find a good bearing, while the oil and parting sand will prevent the loam facing from adhering to the underside of the plate. For the loam to loam joint, the same method is used, but the loam is allowed to set somewhat harder before building the joint against it. The angle of the main joint should be about 1 in 4 inches.

To insure the different parts being put together for casting in exactly the same position in which they were built, a guide surface of loam is smoothed across the joint at three or four convenient points on the outside walls of the mold. These surfaces are each marked differently with the edge of the trowel, similar to the cut at C, Fig. 94.

To properly separate and finish some molds it is necessary to lift away a portion of the mold before lifting the main part. Such a portion is called a draw-back. The draw-back is always built up in position against a pattern or sweep. With the cover plate, which on a smaller scale often serves the same purpose, (see D, Fig. 96), a flat joint is made on the outer wall of the mold, but the cover plate is swept up separately. At No. 3, Fig. 97, is shown a draw-back which carries but a few courses of brick. It may be lifted away by lugs cast in the draw-back plate with little danger of displacing its brickwork in handling.

If the shape of the draw-back renders it impracticable to handle it by the lower plate alone, the brickwork should be bound together by means of hook bolts which clamp on a top plate set sufficiently below the upper joint to be entirely protected from the metal. This upper plate has staples cast in it by which the whole draw-back may be lifted. At B, Fig. 94, the typical construction of such a piece is illustrated. The drawing shows one half the length of the brickwork removed to bring out more clearly the rigging used. The upper end of the second lifting staple shows at *a*, with the loam cut neatly away to allow hooking into the staple.

Where the main core will lift away or will be covered with metal over its top, it must be bound together in a similar manner. This is illustrated in the mold for the marine cylinder, Fig. 97, in which both of these conditions occur.

If a casting has an internal flange requiring thickness of metal underneath the main core, the rigging will be altered to fit these conditions, as shown at D, Fig. 94. In this sketch *a* is a sticker plate and so will carry the loam necessary to face the bottom of the core. To this the small bearing plate *b* is securely bolted by the hook bolt *c*. This plate must set directly upon solid brickwork, as it carries the weight of the entire core. On this bearing plate are cast three studs which firmly support the sticker plate at the required height above the flange surface. The sticker plate carrying this print is filled with loam or dry sand and given a first baking, then swept to a finished surface before being inverted into position. Then the remainder of the core is built up on top and bound together as in the previous example. Another way to form the bottom of this core is to sweep up a dummy flange, *d*, in mud. Set the bearing plate *b* and work in the loam around the studs to form the short "neck" to the level of the top of the flange. Then spread over this flange ½ inch of loam and bed down onto this the sticker plate which has been previously filled with loam and dried, as will be described below. Be sure that the studs on *b* bring up to a firm bearing against the plate *a*, then clamp tight with hook bolts and proceed to sweep up the body of the core.

In case a cover plate must be bedded down against a flat surface, as in the example just mentioned, or must take the impression of an irregular surface on the top of a mold or pattern, as illustrated in Fig. 97, the method to pursue is as follows: After casting, invert the plate and carefully lower it into position and make sure that all fingers clear the surface by at least ½ or ¾ inch. Now set the plate with the fingers up, fill in with loam enough to just clear their tops, leaving the proper openings for runners, risers, tie bolts, etc., and dry thoroughly in the oven. Upon removal from the oven invert and try this loam cover again on the surface it must fit; scraping away any portions which project too much. Now hoist away the cover and coat the face with clay wash. Having previously prepared the surface of the pattern with oil and any loam joint with oil and parting sand, spread an even thickness of fresh loam all over and bed the plate down upon this. The cover plate being still hot will, by the aid of the clay wash, cause the thin layer of fresh loam to dry out and stick fast to the dry loam forming the body of the plate.

BUILDING A SIMPLE MOLD

As an example of a simple loam mold consider a large casting, having the shape of the frustrum of a cone, with a flange at the top and bottom and a flanged nozzle projecting from one side. The section is clearly shown in Fig. 96.

Set the sweep, level up building plate, and building the brickwork as shown in A, Fig. 94, sweep the seat, joint, and bottom surface of flange as shown at A, Fig. 95. The lower flange may be formed by a wooden pattern furnished by the pattern maker, but it is more common to have the sweep made with the small board *x*, which may be removed. By doing this the exact shape of the flange may be swept up without changing the main sweep, as shown at B, Fig. 95. This dummy flange, as it is called, is swept up from fairly stiff "mud." The next step is to seat the cope ring and set the cope sweep, as shown at C, Fig. 95. This sweep shapes the mold for the outside of the casting, for the top flange, and for the top joint of the mold. Loam is thrown, a handful at a time, against the joint and dummy flange, and the engaging faces of bricks rubbed with loam and pressed into position.

When the top of the lower flange is reached in this way, the courses are laid up for about two feet before the loam is spread upon their inner surface and struck off. This method is pursued until the mold is built to its full height.

The projecting nozzle is formed by a wooden pattern; this should be well oiled, and the brickwork and loam laid up under it to support it at the proper level, as given by the center line on the pattern and corresponding line on the sweep. Such projections frequently must be supported in exact position by temporary wooden framework or "skeleton" work until the mold is built up under them.

A finger *y* nailed to the top member of the cope sweep, shapes the guide surfaces on the outside of the mold which are used to center the cover plate in closing the mold. A similar finger exactly the same [illegible] n the spindle, is fastened to the sweep used to form the cover [illegible]e.

[illegible]er the finishing coat of slip has been swept on the surface of the cope, a joint surface about 4 inches wide is struck off flush with the outer face of the nozzle and that pattern is drawn out.

Then the whole cope is lifted off and set on iron supports where it may be conveniently finished with black wash and slicks. It is then baked over night in the oven.

The dummy flange is now entirely removed from the first part swept, the core sweep is set, see D, Fig. 95, and the center core is struck up. This core is t[illegible]d, slicked off and baked. The cover plate is struck off with the [illegible]ers" up, and baked so. This cover carries six 1-inch round [illegible] rough it. These holes will be just over the shell of the metal w[illegible] mold is closed. Five of them connect with the pouring basin a[illegible]ve as runners, while the sixth serves as a riser.

In assembling the mold for pouring, the core is first set on a level bed of sand, the cope is accurately closed over it by the aid of the guide marks, and lastly the cover plate is cl[illegible]ed in position. Now the whole mold is firmly clamped by blocking under the spider, from which wrought iron loops or "strings" connect under the lugs of the building plate, as shown in Fig. 96.

The small core for the nozzle is now set, resting on stud chaplets. The cover plate D is slid over the end of this core and thus holds it firmly in position.

The casing is now placed around the mold and molding sand rammed in to support the bricks against the casting pressure. At the level of the nozzle core, cinders are placed and a pipe leads off to carry away the vent gases. The sand is rammed to about 12 inches over the cover plate and in it are cut the channels connecting the pouring basin and runners. A couple of bricks are set in the bottom of the basin to receive the first fall of metal from the ladle.

In pouring, the runners must be flooded at once and kept so until the mold is full.

In heavy cylindrical castings it was formerly thought necessary to carry the shell of the casting some 6 inches higher than the top flange. This "head" served to collect all dirt and slag that perchance entered the mold with the iron. It was cut off in the machine shop and returned to the foundry as scrap.

With the increased knowledge of iron mixtures this head is now done away with in most instances.

Where a large casting is to finish practically all over, and very clean metal is therefore necessary, overflow channels, connecting with pig beds, are often constructed in modern practice. Then when pouring, the metal is not stopped until a certain percent of it has been flowed entirely through the mold. This of course tends to wash out any dirt which may have gotten into the mold when pouring began.

When the casting is cold the casing and packing sand are removed, as well as the blocking under the spider. Then the whole mold is carried to the cleaning shed where the bricks are removed and the casting cleaned.

BUILDING AN INTRICATE MOLD

As an example of a complex piece of loam work, let us consider the molding of a modern marine engine cylinder, as shown in section, Fig. 97. The example given is that of a double-ported low-pressure cylinder of a triple expansion type. In this case a full wooden pattern should be built, with core boxes for the various dry sand cores that enter into the construction of the mold.

The limits of this paper prevent our going into great detail in this matter; we will, therefore, confine ourselves mainly with an explanation of the drawing, Fig. 97. The heavy building plate has a spindle opening somewhat to one side of its middle to be under the center of the cylinder. Upon this building plate the foundation of the mold is swept, carrying the seat for the cope ring, the bottom face of the flange, and the seat for the main cylinder core. The cope ring No. 1 is made wide enough on one side to carry that part of the mold forming the steam chest. The main cylinder core No. 2, the construction of which has already been explained, is next swept up and lifted away, finished and baked. Now the cope ring is seated and the mold built and struck off for the bottom of the steam chest on a level with the bottom face of flange. Then the pattern may be set. Its position is accurately determined by the main cylinder print and the smaller prints of the steam chest which are bedded into the loam in accordance with measurements along a radial line marked off on the loam surface. With the pattern well oiled the cope is built to the height of the upper flange of cylinder; the entire back of the steam chest core print being left open. The top of the steam chest is lifted off with the draw-back No. 3, which joints at the middle of the upper steam nozzle, and carries that part of the mold to the level of the main cope joint. The two steam nozzles and the exhaust nozzle, may be made with separate cores as explained in D, Fig. 96. By using the draw-back the entire top of the chest core print is left open for convenience in setting the chest and port cores.

The top of the cylinder is jacketed, and through it pass the stuffing box and manhole openings. The flanges of these two openings connect and in the pattern are left loose. The whole top surface is so irregular that it requires three levels of sticker plates to mold it, aside from two small cover plates over flanges.

To the main cover No. 4-4-4-4 with its various length of fingers, is bolted a "crab" 5-5-5 to carry the loam below the flanges of the stuffing box and manhole; and below this again are hung the dry sand cores, No. 8-8-8, forming the jacketed part of the cylinder head. On top of the main cover is fastened a separate plate, No. 6, to shape the top of the upper steam inlet. And at No. 7 a plate with wrought iron bars cast along its edge carries the loam back of the steam chest flange. The small cover plates, No. 9 and No. 10, allow the flanges to be drawn for the parts which they mold.

The pattern is made in many parts so as to properly draw from the mold. When this has been done, all mold surfaces are carefully blackened and slicked before baking.

While the mold proper is being built, the dry sand cores should be made up by the core makers, with the necessary rods, hangers, vent cinders, etc., as described under Core Making.

The manhole core, No. 11, is made with a stop-off piece in the box to give the proper angle at the bottom of the core. It is hung to the cover and clears the main core by 1/8 inch. The stuffing box core rests in a print in the main cylinder core, and is held by a taper print in the cover plate, No. 10.

The jacket cores are hung as shown. The openings made in the loam above the crab, to allow the hook-bolts to be drawn up tight, are stopped off with green sand as previously described. The inlet cores No. 12-12, the exhaust core, No. 13, and the lightening cores, No. 14-14-14, are all bolted directly through the steam chest core, No. 15, to horizontal bars which are long enough to bear against the sides of the mold at the back. The upper inlet core, No. 12, is kept from lifting under the pouring strain by being bolted to the body of the main cylinder core. Stud chaplets are also set between the inlet and exhaust cores to ensure correct thickness of metal at these points.

The vent is taken off from the main cylinder core through the stuffing box core at the top. Sometimes a small ladle full of metal is poured through this opening when the piece is being poured to ensure lighting these gases. The vent for the series of port cores is taken off by ramming a cinder bed up the entire back of the steam chest core, allowing the gases to escape at the top. For safety, also, vents are taken from the bottom of the port and chest cores by the usual pipe vent.

The provision for pouring this mold requires especial attention. Notice the construction of the main basin, No. 16. The long runner, No. 17, leading to the bottom gate, is left open on one side when the mold is built so that it may be easily finished and kept free from dirt. Its open side is closed by cover cores when the mold is rammed up.

Ten or twelve small gates like No. 18 are connected by semicircular channels with the pouring basin, but so placed that no metal shall fall on a core. With the basin arranged as shown, the bottom part of the mold is first flooded with iron. When this has been done the metal is poured in faster so that hot iron is well distributed around the shell of the casting through the small top gates. Should the mold be poured at first from these top gates, the fall of the iron through the full height of the cylinder to the lower flange might result in "cutting" the loam on that surface.

Molds of this size are usually rammed in a pit so as to bring the pouring basin conveniently near the floor. The portion above the floor level is, of course, rammed inside a casing, as described in the previous example.

To guard against uneven cooling strains in this intricate casting, the clamping pressure on the mold is relieved when the metal has solidified, but the sand is not removed from around the brickwork for several days. This allows very gradual even cooling.

It will be noticed that the piston does not work directly upon the inner walls of this type of cylinder. A separate hollow shell or lining is cast of strong, tough iron. This has outside horizontal ribs at top and bottom and middle, which are turned to fit correspondingly projecting ribs seen on the inside of the casting just under consideration. An air space is thus left between lining and main casting which forms a jacket around the bore of the cylinder.

MELTING

The subject of melting the metal which is to be poured into molds is one of the most important considerations in the foundry. It is also one which has received much attention in the last few years, the endeavor being to get away from the old rule-of-thumb methods and to arrive in the iron foundry at something near the precision in resulting metal that is already attained in the brass shops or the steel foundry.

The heat for all melting is obtained from practically the same two chemical elements—namely, *carbon* and *oxygen*, carbon coming from the fuel, be it coal, coke, oil, or gas; and oxygen coming from the air of the blast.

The design of the furnace, the kind of fuel used, and the application of the blast, vary in accordance with the peculiar properties of the different metals and the degree of heat required to melt them.

The melting of steel and of copper alloys will be dealt with under separate headings. We shall now consider only the melting of foundry irons.

Foundry iron is melted in direct contact with the fuel in a *cupola furnace*. The name was derived from the resemblance of the furnace to the cupola formerly very common on the top of dwelling houses.

The cupola consists of a circular shell of boiler plate lined with a double thickness of fire brick and resting on a square bedplate with a central opening the size of the inside of the lining. This bottom is supported some 3½ feet above a solid foundation, on four cast-iron legs. The bottom opening may be closed by cast-iron doors, which swing up into position, and are held so by an upright iron bar placed centrally under them. These doors, protected by a sand bed, support the charge during the heat, and "drop" it out of the furnace when all the iron has been melted. The legs curve outward and the doors are hinged as far back as possible to protect them as much as can be from the heat of this "drop." Several feet above the bottom, there is a door in the side of the stack, through which the stock is charged into the furnace. At one side, level with the bottom, is the *breast opening*, at which place the fire is lighted, and in which the *tap-hole* is formed for drawing off the melted metal. The spout, protected by a fire-sand mixture, projects in front of the breast and guides the metal into the ladles. Oblong openings called *tuyeres*, are placed about 12 inches above the bed, and connect with an air-tight wind-box which surrounds the outside of the stack near the base. The tuyères direct the blast into the fuel, increasing the heat sufficiently to melt the charge. Opposite each tuyère is an air-tight sliding gate with a peephole. This allows the melter to look directly into the furnace.

In the larger cupolas a second set of tuyères is arranged about 10 inches above the main ones. They are used when long heats are run off, to make up for loss of wind caused by the main tuyères becoming partially choked by slag. On cupolas over 36 inches inside lining, a *slag-hole* is provided. This is similar to the tap-hole, and is placed opposite the spout and about 2 inches lower than the main tuyères. Fig. 98 shows a section through a modern cupola furnace, and will need but little further explanation.

In lining the stack, the layer next the shell is usually made of boiler-arch brick about the size of regular fire brick. These are set on end, and should be fitted as tightly together as possible, and laid in a thin fire cement, made of very refractory fire clay and fine, sharp silica sand. The object is to fill every crevice with a highly refractory material. Specially made curved fire brick can be purchased for the inside lining, although some foundrymen use the arch brick for this lining as well. The lining over the tuyères is shaped to overhang them slightly, to prevent melted slag dropping into them during the heat. The lining burns out quickest about 22 inches above the tuyères at what is practically the melting zone. The angle shelves riveted to the shell (see cut) allow this section of the lining to be renewed without disturbing the rest of the stack.

The height of the tuyères above the bed varies with the class of work to be poured. Where the metal is tapped and kept running continuously and is taken away by hand ladles, as in stove-plate work, the tuyères are as low as 8 inches or 10 inches above the bed; while in shops where several tons of metal may be required to fill one mould, the tuyères are as high as 18 inches above the bed. The height of the spout above the molding floor also varies in the same way; for hand

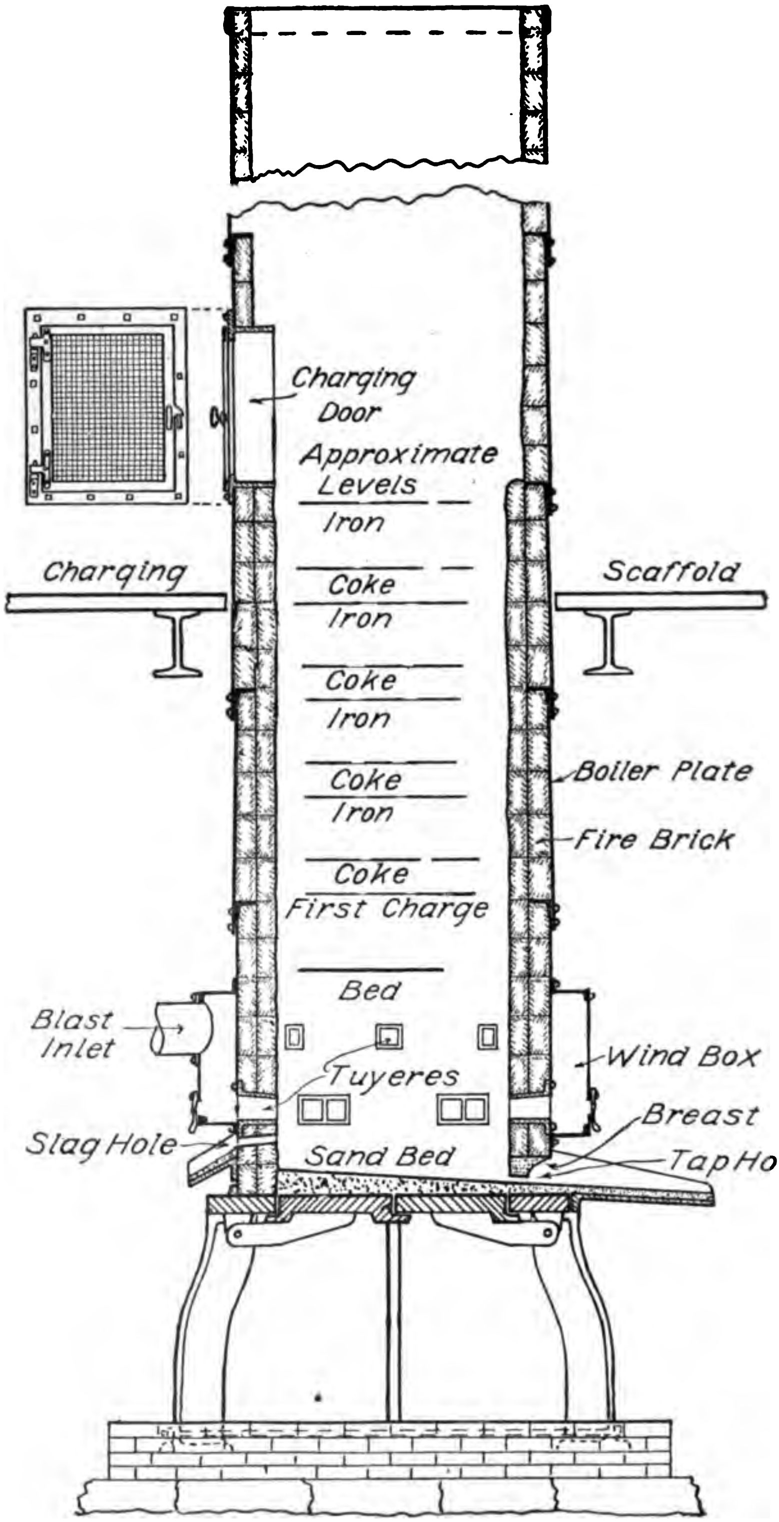


Fig. 98. Section Through Cupola Furnace.

ladle work it may be but 18 inches above the floor, while a height of 5 or 6 feet may be required to serve the largest crane ladles.

The accompanying table, prepared by Dr. Edwin Kirk, gives the approximate height and size of charging door and the practical melting capacity of cupolas of different diameters:

TABLE

Dimensions and Capacities of Cupola Furnaces

DIAMETER, INSIDE LINING	HEIGHT OF CUPOLA	SIZE OF CHARGING DOOR	MELTING CAPACITY PER HOUR	MELTING CAPACITY PER HEAT
Inches	Feet	Inches	Tons	Tons
18	6-7	15 x 18	¼-¾	1-2
20	7-8	18 x 20	½-1	2-3
24	8-9	20 x 24	1-2	3-5
30	9-12	24 x 24	2-5	4-10
40	12-15	30 x 36	4-8	8-20
50	15-18	30 x 40	6-14	15-40
60	16-20	30 x 45	8-16	25-60

A platform or *scaffold* is constructed at a convenient level below the charging door, and all stock is charged into the cupola from this platform. It should be at least large enough to store the stock for the first two charges of fuel and iron.

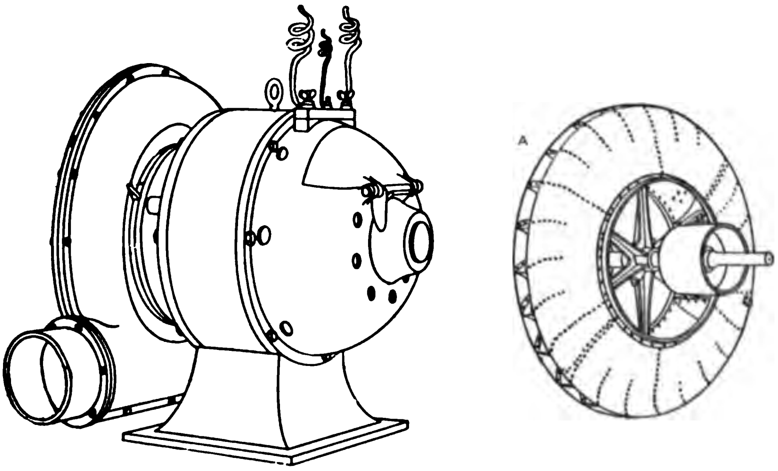


Fig. 99. Fan Blower.

Blast for the cupola is furnished by either a fan blower or a pressure blower. Fig. 99 shows a modern fan blower, the blast wheel for the same being shown at A. The high speed of the blades forces the air by centrifugal action, away from the center of the shaft. The casing is so designed that the blades "cut off" as it were at the top of the main outlet, the air being thus forced through the blast pipe. The current of air is continually being drawn into the fan through the central opening around the shaft.

An idea of the speeds at which blowers should run may be obtained from the following data: An 18-inch blower, at a speed of 4,100 revolutions per minute, gives 5 ounces pressure; a 24-inch at 3,750 revolutions per minute gives 6 ounces pressure; a 36-inch, at 2,900 revolutions per minute gives 10 ounces pressure; a 48-inch, at 2,600 revolutions per minute gives 14 ounces pressure.

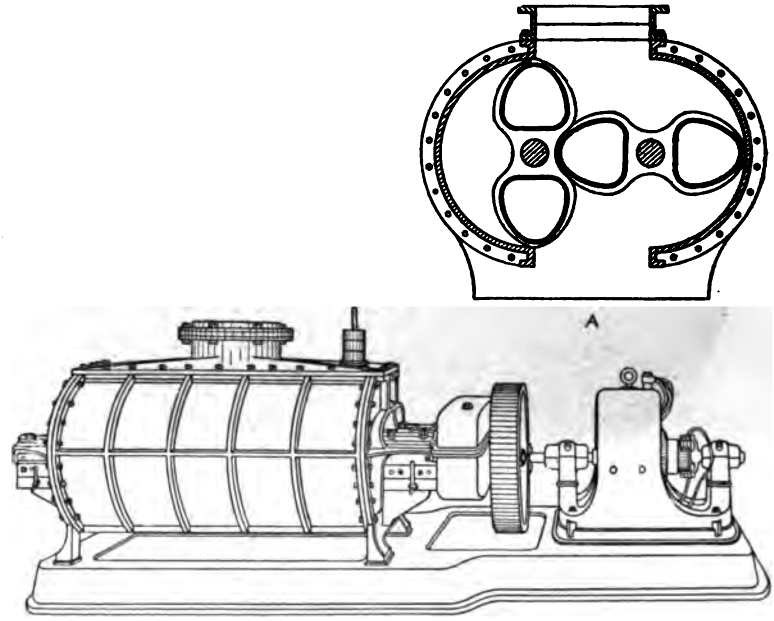
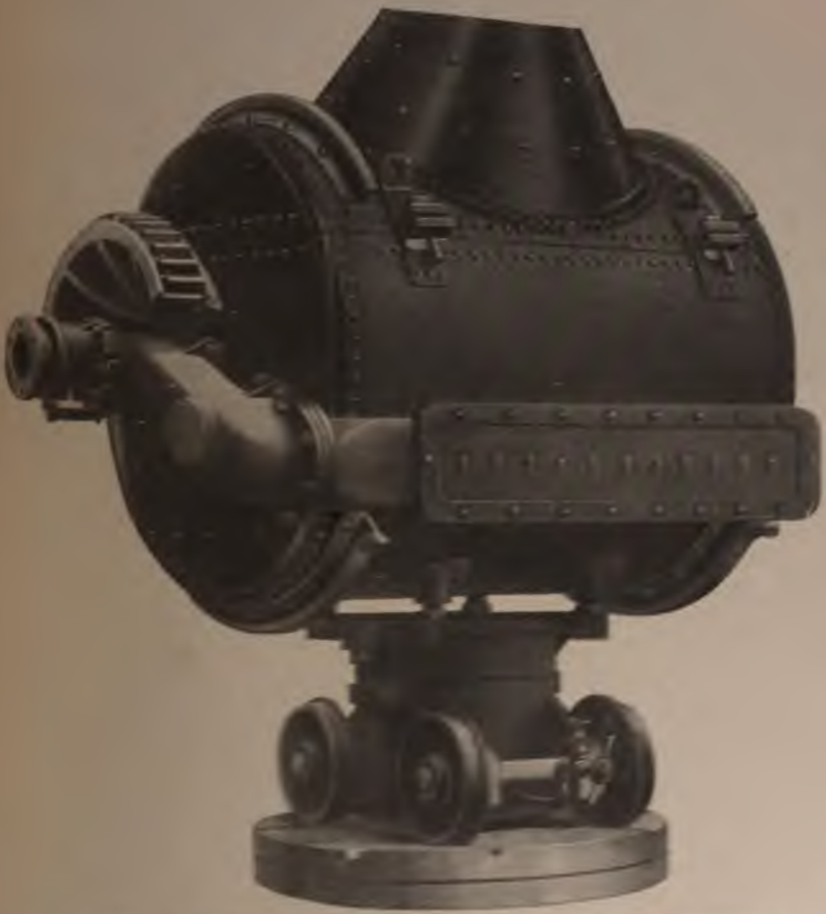


Fig. 100. Pressure Blower.

Since air is very elastic, and the pressure in this case depends entirely upon the centrifugal action of the blades, should the tuyères become clogged, the amount of air forced into the furnace will be reduced proportionately. On the other hand, it requires less power to operate the fan with reduced area of outlet than it does when the discharge is open free.

In the pressure blower shown in Fig. 100, the action is positive,



HYDRAULIC TRANSFER CAR AND TURN-TABLE FOR BISBEE CONVERTER
Allis-Chalmers Co.

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as will be seen from the sectional view (A, Fig. 100). The wipers mesh into each other in such a way that they entrap a quantity of air and force it out of the opening.

The full quantity of air is therefore forced through the tuyères at all times. In such case the power necessary to operate the blower increases as the tuyères become choked and the excessive force of the blast due to choked tuyères is hard on the lining of the cupola.

The cupola should have a blast-gauge attached to the wind-box to measure the pressure of air which enters the tuyères. The pressure should be sufficient to force the air into the middle of the cupola to insure complete combustion. The unit of air-pressure is one ounce. From 8 to 16 ounces is approximately the range usual in cupolas of from 48 inches to 70 inches inside lining.

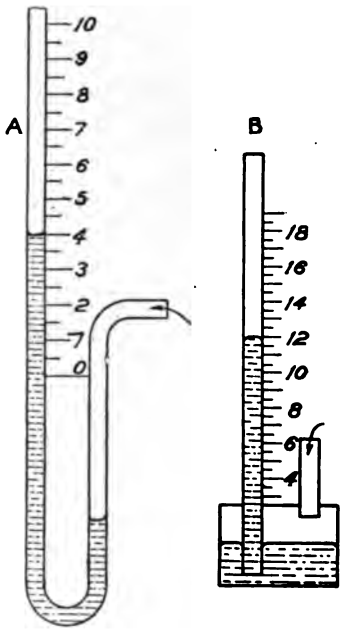


Fig. 101. Wind Gauges.

This pressure is measured by the displacement of water or mercury in a U-shaped tube. With both legs of the tube the same size as in Fig. 101, the graduations on leg A represent the pressure of double that height of liquid, as follows:

With *water:* 1.73 inches height = 1 oz. pressure; then graduations equal

$$\frac{1.735}{2} = .865 = \frac{55}{64} = \frac{7}{8}\text{ in.} - \frac{1}{64}\text{ in.}$$

With *mercury:* .127 inch height = 1 oz. pressure; then graduations equal

$$\frac{.127}{2} = .0635\text{ in.} = \frac{1}{16}\text{ in.}$$

As this would be too small for practical use, mercury gauges are made with increased area exposed to blast pressure (see B, Fig. 101) and are graduated accordingly. (Review chapter on Pressure in Molds.)

OPERATING THE CUPOLA

The following routine must be pursued each time a heat is run off in the cupola:

Clear away dump from former heat.

Chip out the inside of furnace with special hand-pick, removing the lumps of slag which collect about the lower part of the cupola walls, especially above the tuyères. Where the slag coating is comparatively smooth, do not touch it, as that is the best coating possible for the lining.

Daub up with a mixture of fire sand held together with about 1 to 4 fire clay, and wet with clay wash, to a consistency of thick mortar. Smear the surface to be repaired with clay wash; then, using the hands, plaster the daubing mixture into the broken spots in the lining, being careful to rub it in well, especially about the tuyères. The top of the tuyères should be kept slightly overhanging, for the reason already given.

The greater part of the daubing will be required from the bottom to level of melting zone, about 22 inches above tuyères.

Swing up bottom doors, and support by prop of gas pipe.

Build bottom; first cover doors with a 1-inch layer of gangway sand or fine cinders; then ram in burnt sand tempered about the same as for molds. This must be rammed evenly all over the bottom, and especially firm around the edges. Build the bottom higher at sides and back so that metal will flow toward spout. The pitch varies with size of cupola; 1 inch to the foot will answer for cupolas of 24 inches to 30 inches inside lining, while ½ that pitch will do for the larger furnaces.

The cupola bottom should be able to vent so that it will dry out quickly, and not cause the metal to "boil" before the furnace is tapped. It should be strong enough to hold its surface during the heat, but break and drop at once when the bottom is dropped. Too much pitch causes excess of pressure on the *bott*, making trouble in botting up; with too little pitch the metal will not drain well, causing a tendency to chill at the tap-hole. A little daubing mixture should be worked into the sand bottom just inside the tap-hole, to prevent breaking at this point when the tapping bar is forced through.

Lay the fire with shavings, just inside the breast; then fine kindling; then enough large kindling to make sure of lighting a layer of coke sufficient to form the bed. When the gases from the lower part of the bed burn up through, showing that the fuel is well lighted, *level up* bed with addition of a little more coke; and put on *first charge* of iron. Follow this with alternate charges of fuel and iron, to the level of charging door.

Form tap-hole; lay a bar of iron about $\frac{7}{8}$ inches round in the spout, projecting in through the breast opening; fill in breast around bar with a strong, loamy molding sand rammed hard. Recess this in well to leave actual tap-hole as short as possible.

Put on blast when ready for the metal, and leave tap-hole open. *Bott up* when the metal begins to run freely (generally about 7 minutes after blast is on). *Tap* when sufficient metal has collected to supply first ladles.

Bott clay should be mixed with about $\frac{1}{8}$ sawdust, to make it more fragile when tapping. This is made up in small balls, and shaped onto the end of the bott-stick (A, Fig. 102). The tapping bar B has simply a round taper point; C is a gouge or spoon-shape, useful for trimming sides of hole if bott does not entirely free itself when tapped.

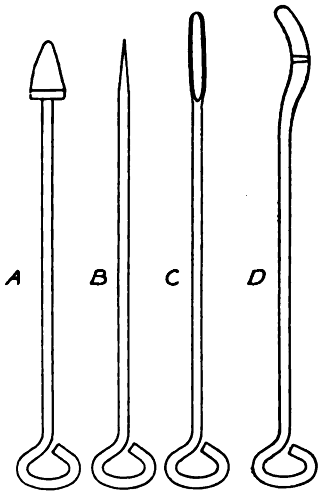


Fig. 102. Tapping Bars.

When all the iron has been melted, *drop the bottom*, by pulling away the bar that supports the bottom doors. Throw water on the dump, by bucket or hose, to deaden the heat, and leave it to cool off over night.

FOUNDRY LADLES

As the melted metal flows from the spout of the cupola, it is caught in ladles. The sizes of these are designated by the weight of metal they will hold; they vary from 30 pounds' to 20 tons' capacity. The names of ladles relate to the method of carrying them. The accompanying table, containing references to accompanying cuts, gives compact data regarding foundry ladles:

TABLE

Data Regarding Foundry Ladles

TYPE OF LADLE	HOW MANAGED	CAPACITY (pounds)	SIZE (inches)			WEIGHT OF LADLE
			Top	Depth	Bott'm	
			Thickness for Lining			
Hand Ladle A, Fig. 103	Hand shank	30-50	7-8 ¾	7-8 Side ½	6-7 ½-¾	15-16 lbs.
Bull Ladle B and C, Fig. 103	Single or double shank	80-350	9-15 1¼	9-15 ½-⅝	8-13 ¾-1	35-100
Crane or Trolley Ladle Like C, with bail	Bail with single or double shank	300-2,000	14-26 1¾	14-26 ⅝-1	12-23 1-3	115-350
Geared Crane Ladle Fig. 104	Worm gear on heavy bail	1,000-35,000	20-75 2-4	20-60 1-4½	18-66 1½-5	1,900-7,000

In the three columns under "Size," the larger figures give the dimensions inside of ladle shells. The smaller figures refer to the thickness of the lining at the top, sides, and bottom of the ladles.

Hand ladles are made of cast iron or pressed steel. The larger ladles are built up of boiler plate. Cast iron is poured from the top of the ladle, which should therefore be provided with lips. Ladles must be lined to protect them from burning through. Up to one ton capacity, the cupola daubing mixture is used. The bowl is smeared with thick clay wash, and the clay pressed in hard with the hands, being rubbed smooth on the inside. The lining should be kept as thin as possible, ⅝ to ¾ inch on hand-ladles, 1 inch to 1½ inches on large ones; the bottom lining from ⅓ to ½ thicker than sides, as it receives the first fall of the incoming metal.

The larger ladles are first lined with fire brick of thickness proportionate to their size, and then daubed on inside with clay mixture similar to cupola lining. The lining must be well dried before use, to drive out moisture. In stove-plate and hardware shops, where most of the pouring is done with hand ladles, a special ladle-drying stove similar to a shallow core oven is provided. A wood fire is built inside of the larger ladles to dry them out. To preserve a lining as long as possible, slight breaks are repaired daily. As with the cupola, the slag formed by the hot metal forms the best coating possible for inside lining.

POURING

The first thing to be considered here is skimming off the slag which collects on top of the metal. This should be done on larger ladles before leaving cupola, and again while metal is being poured. For this, a long iron rod is used, with blade shaped as in D, Fig. 102. This is rested across top of ladle near lip, and effectively holds the slag back; the long handle permits the skimmer to stand well back from the heat of the metal. On small ladles, skimmers are of course shorter, and the end is bent up more for convenience, as the ladles will be much nearer the floor when pouring with them.

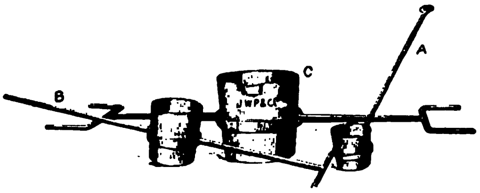


Fig. 103. Hand and Bull Ladles.

Hand and bull ladles are shown in Fig. 103, while Fig. 104 shows a crane ladle.

Much skill is required in pouring a mold. A molder must know the character of the work, and judge whether it must be poured fast or slow. In general, light work cannot be poured too fast. Heavier work is poured more slowly. Care must be exercised to keep the stream steady from the first, and not *spill* into the mold, as this may

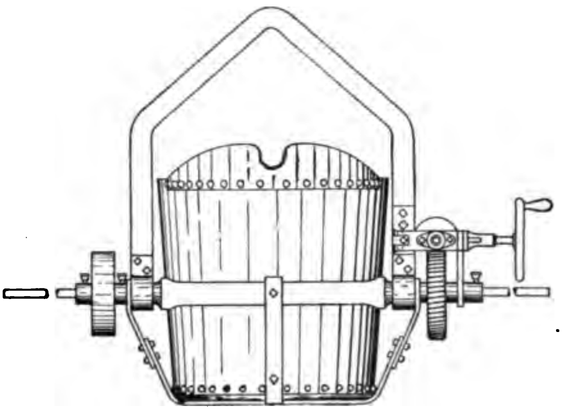


Fig. 104. Crane Ladle.

cause "cold shuts" or leave "shot" iron in the castings. The runner basin must be kept full, for gates and runners are made with this express purpose in view, as has been stated previously.

Metal must not be allowed to chill or "freeze" in the ladle, as this would destroy the lining when it came to removing the cold metal. Metal left in the ladles when the mold is full, must be poured back into a larger ladle or emptied into a convenient pig bed. These are built in a sand bed usually near the cupola, or stout cast-iron pig troughs or chills are provided. They should taper well on the inside, holding about 50 pounds each. Some are arranged to swing on trunnions for convenience in dumping. They should be smeared with a heavy oil and dusted with graphite, to prevent the metal sticking in them. It is safer to heat these pig molds as well, so that no moisture will form and cause a "kick" or explosion when hot metal is first poured into them.

CUPOLA MIXTURES

By this term is meant the proportioning of the various pig irons and scrap that make up cupola charges, with the object of obtaining definite physical and chemical properties in the resulting castings.

The requirements of castings vary; and metal that would be good if run into thin stove-plate, would be entirely too soft for heavy machine castings. Again, iron that might answer all requirements of a bed plate would not be strong and tough enough for steam cylinder work. The one in charge of this work, therefore, must so mix the different irons that his castings shall be soft enough to machine well if necessary, and at the same time be hard enough to stand the wear and tear of use.

Formerly the appearance of the fracture of a pig or scrap was the sole guide in determining mixtures. Unquestionably the fracture of iron indicates to the experienced eye much as to its physical properties. But this method of mixing has repeatedly proved misleading.

Representative practice to-day recognizes chemical analysis of the various irons as most essential to the proper mixing. Many firms now buy their pig iron, and many other allied supplies, by specification; and the chemical analysis of the iron must show that its various metalloids come within certain limited per cents.

To understand, then, these modern methods, we must consider the subject of the chemistry of iron.

CHEMISTRY OF IRON

An element, in chemistry, is a form of matter which cannot be decomposed, or, in other words, cannot be broken up into other forms by any means known to science.

Iron is such an element; but absolutely pure iron is of no commercial value; it is only when it is combined with impurities—or, as we must recognize them, other chemical elements—that mankind is interested in it.

In the forms of iron with which we are dealing, pig iron and cast iron, five elements are considered as affecting their physical properties. These elements are Carbon, Silicon, Sulphur, Phosphorus, and Manganese.

Carbon is the most important and most abundant of all the chemical elements. It forms the principal part of many substances in daily use about us, such as coal, coke, lead pencils, graphite facings, etc. In its relation to iron, it is peculiar in that it occurs in iron in two forms. One is in a chemical combination forming a hard substance with a fine grain, of which tool steel is the purest type. The other is simply a mechanical mixture forming minute facets of free carbon interposed between the crystals of the combined form. It softens cast iron, but weakens it by causing larger crystals to form. Drawing the finger across a freshly cut surface or fracture of cast iron, some of this free carbon will be rubbed off, and will show as dirt on the finger. We shall use the term *graphite* in referring to this form of free carbon, and the term *combined carbon* in referring to the element in its combined state.

Silicon of itself is a hardening element in cast iron, but on account of its marked influence upon carbon formations, it is usually considered a softener. During the cooling process, silicon retards the formation of combined carbon, thus increasing the formation of graphite in proportion to the increase of silicon. At the same time, through its own influence on iron, it preserves the fine character of the grain, and so maintains the strength of the casting. In other words, within certain limits, the addition of silicon softens castings without impairing their strength. It makes iron run more fluid, and reduces shrinkage. Silicon varies in castings from 1.50 to 2.50 per cent.

Sulphur is the most injurious element in iron. It makes castings hard, red-short, and tends to the formation of blow holes. At the melting temperature, iron will absorb sulphur from the fuel—a decided reason why foundry coke should be as free as possible from this element. Sulphur in castings should not exceed .07 per cent.

Phosphorus tends to make iron run very fluid when melted. It is a hardener. For machine castings it should not exceed 1 per cent.

Manganese strengthens, and of itself hardens iron. Chemists are beginning to consider its proportions more carefully, in the belief that under certain conditions it acts as does silicon, softening the castings while retaining their strength. It is usual to keep it below .5 per cent.

The strength of a casting and the finish which it is capable of taking, are largely dependent upon its having a fine, even grain. We have seen that the proportions between the combined carbon, the graphite, and the silicon have decided influence upon this condition. But the rate of cooling must also be taken into account. A thin casting cools rapidly, tends to increase the combined carbon, and without the influence of silicon would be hard and brittle. In a heavy casting, the metal stays liquid longer, more graphite is thrown off, and the casting is naturally softer.

Therefore light work requires a larger proportion of silicon to counteract the effect of the rapid cooling than does larger work.

Modern practice makes daily analysis for the two carbons, the silicon, and the sulphur, occasionally testing for the other elements to see that they are kept within their safe limits. Silicon, however, is used as the guide for regulating mixtures. The following shows good proportions of silicon for different classes of work:

Steam cylinders	1.70 per cent
Medium heavy work (½ inch to 2 inches thickness)	2.0 " "
Light work (less than ½ inch thickness)	2.50 " "

A more complete analysis of results to be aimed for is:

	Si.	P.	S.	Mn.
Automobile cylinders	2.25	1.	.075	.5 per cent
Corliss engine cylinders (1¼ to 1½ inches thickness)	1.20–1.70	Below .1	Below .095	" "

To calculate for any result, we must first know the analysis of the irons to be used in making the charge. We shall consider silicon as the guide

With a firm keeping track of results, the proportion of silicon in their "home" scrap can be accurately estimated. With miscellaneous machinery scrap, this is more difficult. The following, however, are safe estimates:

Small, thin scrap	2 –2.4	per cent
Large scrap ranges	1.50–2	" "

The analysis of pig iron is made from drillings taken from a fresh fracture. Between the very fine grain about the chilled sides of the pig, and the very coarse grain in the center, average-sized crystals will be noticed in the fracture. It is here that the drillings for analysis should be made, as indicated in Fig. 105. About a ¾-inch flat drill is best to use, as it cuts a more uniform chip from the varying grade of pig than does a twist drill.

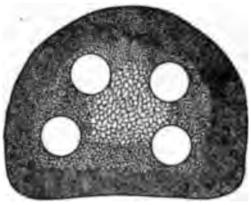


Fig. 105. Analysis Section.

To determine the analysis of a carload lot of pig iron, the following method is employed. Select ten pigs which will represent an average of the close, medium, and coarse-grained iron in the car. These pigs should be broken, and drillings taken from the fresh fracture. The drillings from these ten fractures are thoroughly mixed together, and about two ounces by weight, or a large tablespoonful by measure, is sufficient for the chemical analysis. The result is taken for the average analysis of the carload.

The smaller foundries who do not employ a chemist can get a good working analysis of their iron from the furnace from which it is bought. Or, in many cases, sample drillings are sent to a practicing chemist.

The proportions of silicon and sulphur contained in the ordinary grades of pig iron are approximately as follows:

GRADE	SILICON	SULPHUR
Ferro-silicon	7 –12 per cent	.03 per cent
Silvery	3 – 5 " "	.03 " "
No. 1 Foundry	2.50– 2.90 " "	.03 " "
No. 2 "	1.95– 2.40 " "	.04 " "
No. 3 "	1.40– 1.90 " "	.05 " "

When we have the analysis of our iron, we can proceed to calculate the mixture, bearing in mind that some of the silicon will be burned out of the iron during the heat. From .15 to .25 per cent is a fair estimate for this loss in cupolas ranging from 36 inches to 72 inches inside lining. This loss must be deducted from the final estimate.

It is proposed to make a mixture, using three of the following irons, for miscellaneous machinery castings which require about 2 per cent silicon. And we wish to use one-half scrap:

Silvery	4	per cent
No. 1 Foundry	2.65	" "
No. 2 "	2.22	" "
No. 3 "	1.75	" "
Scrap "	2.00	" "

The student should bear in mind that the sign of *per cent* means $\frac{1}{100}$ = .01. To multiply a whole number by per cent, set the point two places to the left; thus 35 per cent of 5,000 = .35 × 5,000 = 1,750.

To multiply per cent by per cent, set each point one place to the left before multiplying and the result may be expressed as per cent; thus 25 % of 35 % = 2.5 × 3.5 = 8.75 per cent.

Then we have:

A	B	C	D
No. 1	25. % ×	2.65 % =	.6625 %
No. 2	20. % ×	2.22 % =	.4440 %
No. 3	5. % ×	1.75 % =	.0875 %
Scrap	50. % ×	2.00 % =	1.0000 %

Total, 100. % of charge has 2.194 % Silicon content.
Deducting for loss in heat .20 %
1.994 % Estimated silicon in result.

Or, with a No. 2 iron and Silvery:

A	B	C	D
No. 2	45. % ×	2.22 % =	.999 %
Silvery	5. % ×	1.00 % =	.200 %
Scrap	50. % ×	2.00 % =	1.000 %

Total, 100. % of charge has 2.199 % Silicon content.
Deducting for loss in heat .17
2.029 % Estimated silicon in result.

In these examples, column A is the kind of iron; B, per cent of this iron used in charge; C, per cent of silicon in single grade of iron; D, per cent of silicon to whole charge as supplied by each grade.

One or more per cents in column B are usually decided upon before beginning calculations, and then the others are varied until the desired silicon content is obtained.

With this as a guide, it is a simple matter to find the actual weight for each grade, to make up any size of charge. For example, we wish to put 5,000 lbs. on bed and 3,000 lbs. on other charges, using first mixture:

From column B.		Bed.	Other charges.
No. 1	25 % × 5,000 =	1,250 lbs.	750 lbs.
No. 2	20 % × 5,000 =	1,000 "	600 "
No. 3	5 % × 5,000 =	250 "	150 "
Scrap	50 % × 5,000 =	2,500 "	1,500 "
		5,000 lbs.	3,000 lbs.

PRINCIPLES OF MELTING

Combustion cannot take place without oxygen, of which the air is the most abundant source of supply. For example, in the incandescent electric light, a strip of carbon is heated to a white heat; but it does not consume, or burn up, because all air has been exhausted from within the globe.

In the cupola furnace, both coal and coke are used as fuel. They consist largely of carbon, and, after being lighted by the kindlings, are kept at a glowing red heat by the natural draft through the open tuyères. The blast supplies the oxygen necessary for a melting heat. The quantity of air forced in by the blast cannot be entirely taken up by the layers of fuel immediately above the tuyères; thus complete combustion does not take place until a distance of 18 to 23 inches above the tuyères is reached. This is termed the *melting zone*. It is the aim of the melter to keep the top of his bed as nearly as possible at this level, so that the iron resting on it shall be exposed to this intense heat and melt rapidly.

As the fuel of the bed burns away, this level tends to be lowered. But the iron on top of it melts, and drops to the bottom of the cupola; and the subsequent charge of coke restores the level of the bed for the next charge of iron; and so on.

FUEL

Both anthracite coal and foundry coke are used in the cupola. Coal, owing to its density, will carry a heavier load than coke, but it requires greater blast pressure, and will not melt as fast as coke. Coke, for foundry use, should be what is known as "72-hour" coke, as free as possible from dust and cinders. Coke is made up of a sponge-like "coke" structure which is almost pure fixed carbon, and an open, "cellular" structure which makes it especially valuable as a furnace fuel because it is so readily penetrated by the blast.

A representative analysis of a strong 72-hour coke is as follows:

Moisture	.49 per cent
Volatile matter	1.31 " "
Fixed carbon	87.46 " "
Sulphur	.72 " "
Ash	10.02 " "
Cellular structure	50.04 per cent
Coke structure	49.96 " "
Specific gravity	1.89
Heat units per pound	12,937

FUEL TO IRON

The proportions of the bed fuel, first charge of iron, and subsequent charges of fuel and iron, vary greatly with the size and design of the cupola, the grade of fuel used, and the method of charging.

To determine the right amount of fuel for the bed, the most practical thing to do is to "cut and try," especially with a new equipment.

For a 36 to 48-inch cupola, average 22 inches above the tuyères, with a 10-ounce blast to start with, the best way to proceed is to chalk off this distance inside the cupola before daubing up. Then, from a ½-inch rod of iron, bend a shape like Fig. 106. The distance *a* equals the distance from the mark inside cupola to about 4 inches above bottom of charging door. When the coke is well lighted, before charging the iron, level off bed according to this gauge. The safe side is to have the bed too high. If the bed is too high, it will show by slow but hot metal; if too low, the metal will be dull. After first heat, the height may be adjusted until proper melting is obtained; then try always to work to same height. The weight and character of the coke charged on the bed should be carefully noted.

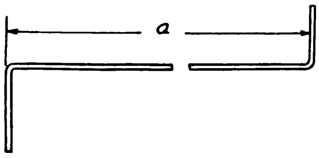


Fig. 106. Bed Gauge.

No fixed rule for general application can be given for proportioning the alternate charges of iron and fuel. From 4 to 6 pounds of iron may be melted to one of heavy coke on the bed; about ⅓ less, for light coke.

Intermediate charges of coke should be just sufficient to preserve the upper level of the bed. The layer will usually be about 6 inches thick. Its weight should be carefully taken.

Subsequent charges of iron may be made 8 or 10 pounds to one pound of coke put between charges.

The action of the furnace must be carefully watched, with the aim to make it melt the iron charged as rapidly as possible and bring it down white hot. Also, bring the ratio of iron to fuel as low as may be, without sacrificing either of these other objects.

SAND MIXING

When a mold is poured, the intense heat of the iron burns out those properties in the sand which give it its bond, making it necessary that a certain proportion of new sand shall be mixed with the heap sand and used as facing. See explanation in earlier paragraphs.

The facing sand should be mixed daily for the molders by one or more of the laborers, at a place convenient to the storage sheds and molding floors. A hard, smooth floor of clay or of iron plates is a great advantage.

The proportions of the different sands are measured by shovel, bucket, or barrowful, and spread over each other in flat layers, sufficient water being sprinkled on to temper the pile. The sand is then cut through once with the shovel, then put through a No. 2 sieve, all lumps being broken up and refuse thrown out. It is next put through a No. 4 sieve, and thrown in a pile ready for use.

When this work is done by hand, the ordinary screen sieve commonly employed by masons is used for the riddling, and a round foundry riddle for the final sifting. To reduce the labor of this, the

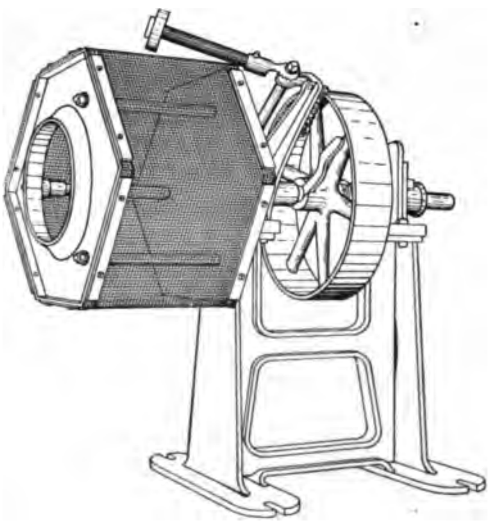


Fig. 107. Rotary Sieve.

riddle is slid back and forth on a pair of parallel bars supported conveniently above the storage pile.

There are two classes of labor-saving machines used in mixing facings, core sand, etc.—those which mix by riddling, and those which mix by a combined breaking and stirring action. There is great variety in the styles of these machines on the market. The illustrations show the typical mechanical devices in use.

Fig. 107 is made with wire on one or both ends, and is driven by belt or connected motor. Sand shoveled into the central opening is sifted in a pile on floor, or direct into barrow. The rubber hammer on top automatically raps each face of sieve as it revolves, knocking the meshes free from sand.

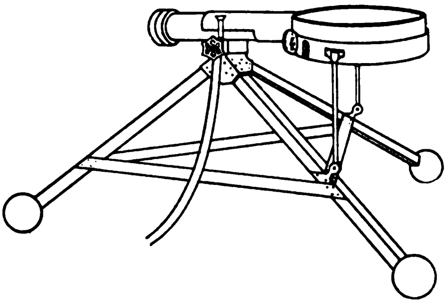


Fig. 108. Sand Shaker.

Fig. 108 shows one of the latest labor savers in this line. Here a foundry riddle is supported in a metal ring attached to the piston of the machine. It is made to vibrate rapidly by means of compressed air or steam. These shakers are made with portable tripod, as shown; they are also made stationary or are fastened on a post by means of a swivel joint, to be swung

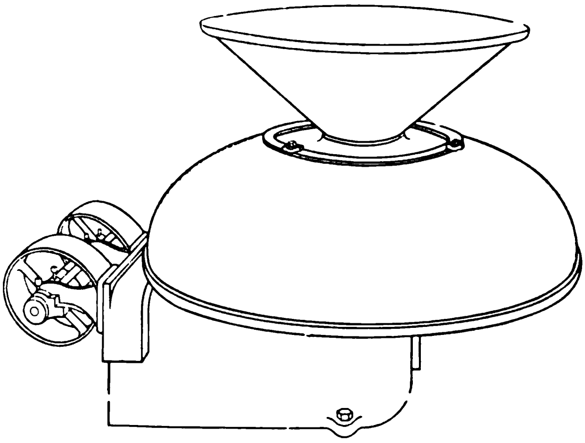


Fig. 109. Centrifugal Mixer.

over a wheelbarrow or over a molding machine, and out of the way again when not in use.

Fig. 109 shows a centrifugal mixer. Inside of the umbrella casing a horizontal plate about 12 inches in diameter and carrying a number of vertical steel pin about 6 inches long, is fastened to the top of a short upright shaft driven by a belt running inside of the casing shown at the base of the machine. The machine runs about 1,500 R. P. M.; and sand shoveled into the hopper is very evenly broken up by the pins and thrown against the steel hood, breaking and shattering any lumps of clay or loam and making a very uniform mixture. The hopper may easily be removed to clean the plate. The machine is used for the final mixing.

Fig. 110 shows a foundry grinder or facing mill. It is the type of mill used for mixing loam. Either the pan or the rollers are attached to the driving shaft and made to revolve, crushing and mixing whatever is shoveled into the pan. Frequently, a stout blade, something like a plowshare, is fixed between the rollers, and prevents the mixture caking to the bottom of the pan. The faces of the rolls are of very hard or of chilled cast iron to withstand wear.

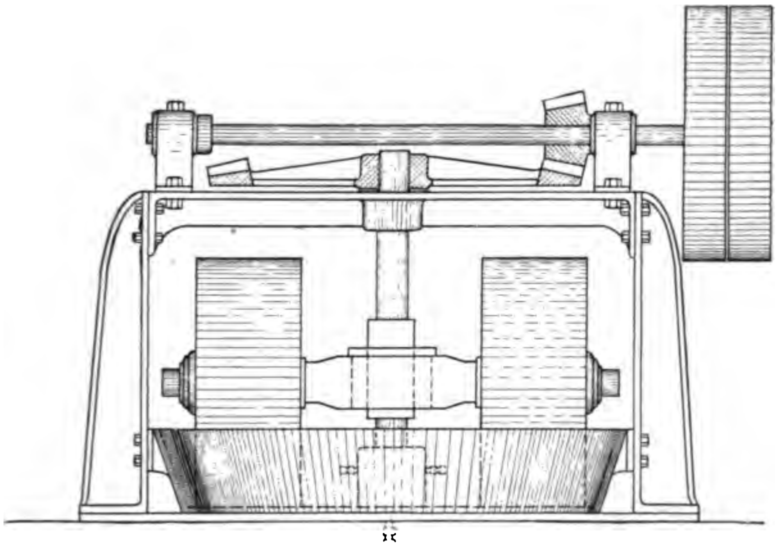


Fig. 110. Facing Grinder.

When the loam mixture is sufficiently ground, it must be shoveled from the pan, and delivered to the molders or stored temporarily. It will "set" if stored too long.

This is the type of mill used in the steel foundries, for grinding the facing materials. The various sands are dumped into the pan at one side, and, when ground sufficiently, are shoveled directly from the pan into a centrifugal mixer. This prepares them for use.

CLEANING CASTINGS

After a casting has solidified in the mold, the flask should be removed, leaving the casting in the sand. For light bench work and snap flask work, the mold is lifted bodily and the sand dumped on the pile, the bottom boards piled in one place, and the cases piled in another ready for the next day's work. As the molds are dumped, the castings are removed from the sand and piled at edge of gangway. When all castings have been removed from the sand, the gates are broken and thrown in a pile by themselves. When cold enough to handle, the castings are removed to the cleaning room, and the gates and sprues to the scrap pile. With heavier floor work, the clamps are removed as soon as the casting has set; the flask is rapped with a sledge hammer and stripped off the mold, leaving the castings to cool gradually in the sand. Sometimes a sharp blow is given on top of the runner while it is still red; this breaks it off before the flask is shaken out. At a red heat, cast iron is very weak and can easily be broken.

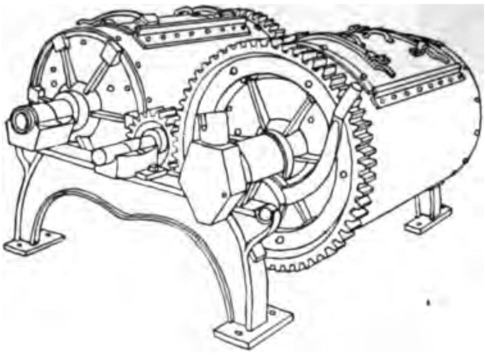


Fig. 111. Dustless Tumbling Barrel.

The most effective way to clean small castings is in a rattling barrel. Fig. 111 shows a modern set of dustless barrels. The shell of the barrel is ⅝-inch boiler plate riveted to cast-iron heads, with a door arranged to be entirely removed for packing and dumping. The bearings are hollow, and from one end the dust is drawn off through a galvanized iron pipe. This pipe connects with an air-tight wooden chamber (Fig. 112) varying in size with the number of barrels

connected with it. In this chamber hang a number of cloth-covered screens. An exhaust fan is connected to this chamber at the opposite end from the inlet pipe.

When the fan is in operation, a strong current of air is drawn through the barrels and through the chamber. The dust, entering the chamber, settles on the screens, so that but little dust escapes to the outside air.

When necessary, the exhaust is stopped, and, by means of a crank on the outside of the dust chamber, the screens are shaken and the dust drops off, when it can be removed through a trap into an ash can or wheelbarrow.

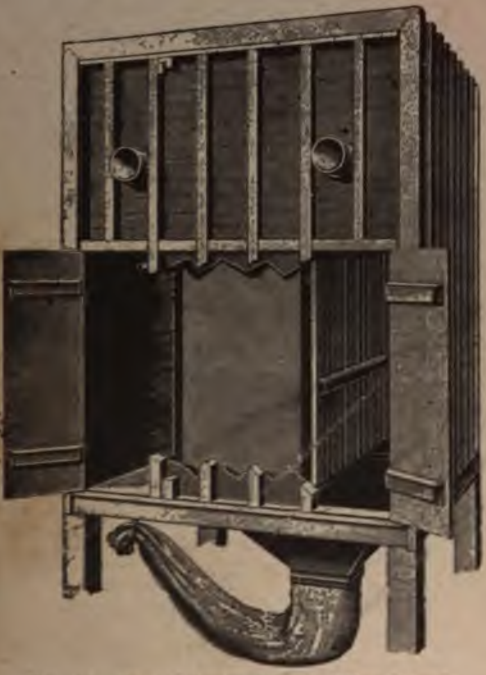


Fig. 112. Dust Collector for Tumbling Barrel.

The driving shaft carrying the pinion revolves all the time, and any barrel may be thrown over into gear or drawn out of gear by the operation of a hand lever. The barrels should run about 25 R. P. M. Each barrel should be packed as full as possible with several shovelfuls of gates, shot iron, or hardened stars thrown in with the castings. The cleaning is accomplished in from twenty minutes to half an hour by the scouring action of castings, scrape, etc., rubbing against one another. Castings up to 50 or 100 pounds can be rattled but only those of a similar character as to design or weight should be packed in together; otherwise the lighter castings will be broken by the heavier. When removed from the barrel, the work should show a smooth, clean surface of an even gray color.

From the rattlers, castings go to the grinding room, where projecting gates or other slight roughness is removed on the emery wheel.

Heavy castings are cleaned by hand, by pickling, or by sand blast. When cleaning by hand, the worst of the sand is rapped off by light hammering, the remainder scraped off with old files and steel wire brushes (Fig. 113, A). Some shops rub off finally with broken pieces of coarse emery wheel. Risers and fins are removed with cold chisels. The pneumatic chisel shown in Fig. 113, B, is used as a time-saver. Where work is light enough to handle, small fins are removed by emery wheels; medium coarse wheels will cut faster on cast iron than fine ones, and will hold their shape better.

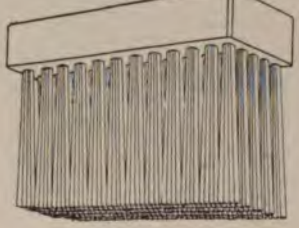


Fig. 113 A. Steel Bristle Brush.

It is when castings must be cleaned by hand, that value of a good facing dust shows itself. With the proper facing, the sand cleaves readily from the casting, leaving a fine-looking, smooth surface. With poor facings, on the other hand, the iron burns into the sand, making it hard to clean, and leaves a rough surface on the work.

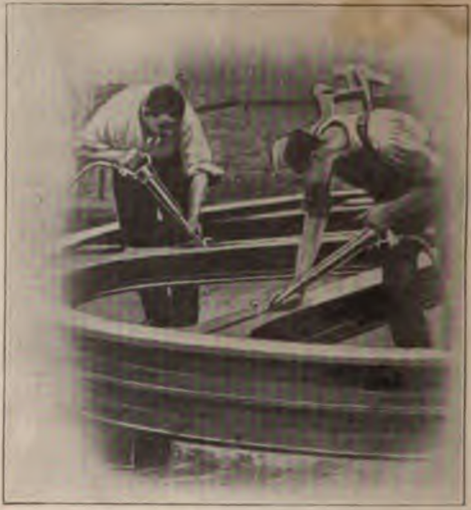


Fig. 113 B. Pneumatic Chisel.

Pickling is a method of cleaning resorted to where there is much machining to be done on a casting. The work is placed in a pile on a suitable platform, and dilute sulphuric acid is thrown over it during one day, frequently enough to keep it well wet. The platform should be arranged to drain the acid back into the vat. Acid is diluted from 1 to 8, to 1 to 10. After about 12 hours' bath with acid, the castings are washed clean with hot water. The acid acts on the hard skin of oxide of iron, which forms when the iron strikes the damp sand, and eats through this skin to the iron itself.

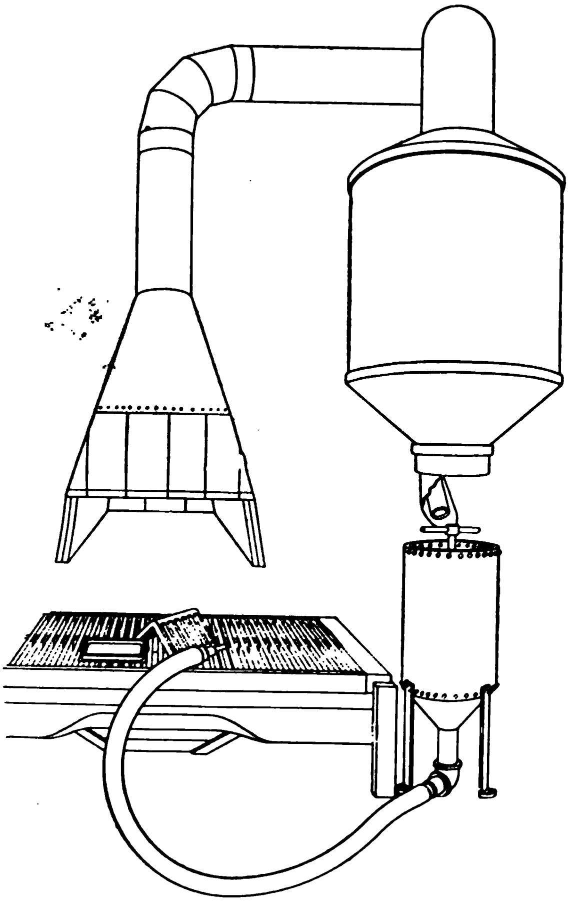


Fig. 114. Sand Blast.

The washing water should be hot enough to warm the castings sufficiently for them to dry rapidly without rusting. The acid must be thoroughly washed off, or it will continue to eat into the iron and cause a white powder (sulphate of iron) to form on the surface.

constructed with a good head of metal in risers, and they are poured under pressure. The shrinkage is double that of iron; the risers are made very large, and are placed directly on the casting to insure feeding well. Great care must be exercised that neither mold faces nor cores bind during cooling, as such binding might cause a flaw.

When two surfaces meet at right angles, the corner will remain hot longest, and the sides will shrink away, tending to cause a fracture at *a*, Fig. 116. To overcome this, thin webs are cut by the molder about every 4 inches or 6 inches—shown at *b*. These cool first, and hold the adjacent sides in position, preventing them from pulling away from each other. The internal strain due to this cooling is relieved by the annealing. After the casting is annealed, the webs are cut away.

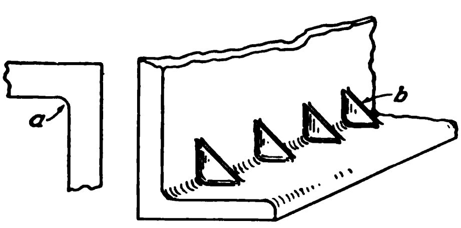


Fig. 116. Shrinkage Webbs.

STEEL FACING MIXTURES

To withstand the high heat, pure silica sand is used as the basis of the facing mixtures for steel molds. Pure quartz or silica rock is quarried, and reduced to a sand form through a series of rock crushers.

At the foundry the necessary bond is given by the addition of fire clay and molasses water. These are thoroughly mixed with the sand in a facing mill and mixer (Figs. 109 and 110). A typical mixture is as follows:

1 barrow Silica Sand;
3 pails powdered Fire Clay;
Temper with molasses water.

Where quartz sand is very expensive, the mixtures made as follows will reduce the cost. The old crucibles and fire brick should be crushed separately in the mill before mixing.

INGREDIENTS	FOR CASTINGS UP TO 2 INS. THICK.		FOR CASTINGS OVER 2 INS. THICK.	
	I	II	III	IV
Old facing sand	8 parts	12 parts	1 part	
Old crucibles	2 "		10 parts	
Fire Brick	2 "		5 "	
Fire clay	2 "	1 part	3 "	1 part
Coke	1 part		1 part	
Silica sand		5 parts		5 parts
Graphite		2 "		

Temper with molasses water.

For *facing wash*, these mixtures are ground very fine, and thinned with molasses water.

Core sand for steel work is practically the same mixture as the mold facing. For thin metal a somewhat less refractory natural sand may be added to reduce cost of mixture.

For *small round or flat cores*, $\frac{1}{20}$ part rosin, with silica sand, tempered with molasses water, makes a good core. It should, however, be thoroughly burnt.

For *core wash* mixture, use 3 parts Silica flour; 1 part Ceylon graphite; molasses water.

STEEL FLASKS

Flasks for steel work are built up of cast iron (see Fig. 4). Full-length crossbars are bolted in the cope, 6 inches to 8 inches on centers, depending on size of flask. Short crossbars are fastened between these as needed, say 12 inches to 16 inches on centers (see Fig. 117).

Oblong bolt holes 4 inches on centers are cast in the sides of the flask and in all crossbars. Slots to correspond are cast in flanges of bars, so that they may be readily removed or shifted when fitting cope to pattern.

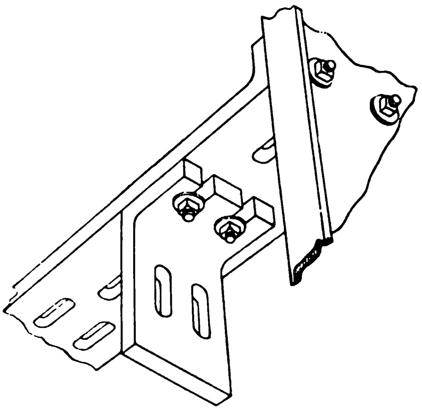


Fig. 117. Short Crossbar.

The holes for pins should be drilled to template in all flasks of the same size, so that copes and drags may be interchanged. Flask pins are slipped through holes temporarily when flask is being closed or opened. On large work the cope is bolted to drag while being rammed.

The bottom plate is of cast iron, and is clamped to flange of drag with short clamps and steel wedges.

Flasks of from 18 inches to 48 inches in length have two handles bolted on ends to lift them with. Larger flasks have trunnions, rockers, or U-shaped handles cast on the sides.

For details of cast-iron flask, see Fig. 4.

Fig. 118 shows type of convenient small flask built up of channel and angle iron, size 14 by 20 to 24 by 48 inches. The same tools are used for packing and finishing mold as described in connection with iron molding.

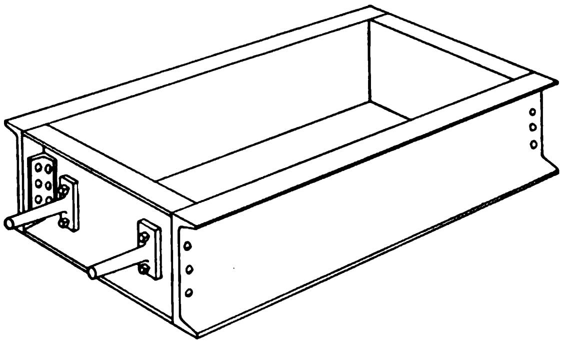


Fig. 118. Small Flask for Steel Molds.

PACKING THE MOLD

In packing the mold, place the pattern on board and cover with 1½ to 3-inch of facing, depending on size of job. Tuck well with fingers. The facing is used as prepared by the mixer, not sifted. Set drag on board, shovel in heap sand, and ram mold somewhat harder than for iron. "Strike off" and seat bottom plate, fastening it firmly to flange of drag with clamps or bolts. Roll the mold over, and remove mold board

Press with the fingers all over the joint surface, especially around the pattern, to make sure of firm packing.

If soft places are found, they should be tucked in with facing sand.

When needed repairs are made, slick the joint all over. Use burnt core sand for making the parting. Try on cope and adjust bars to fit pattern. Clay wash the cope before packing. Put on necessary facing over joint and pattern. Set the gate on joint, but place risers directly on pattern. Set necessary gaggers, shovel in heap sand, and ram the cope. Vent well, lift cope, moisten edges, and draw pattern.

In finishing the mold, nails are used freely (about 1½ to 2 inches apart), driven in with heads flush with surface of sand. This is to prevent the cutting of the surface by the rush of hot metal when mold is poured.

It is at this stage that the thin webs previously mentioned, are cut into the corner fillets where needed. The whole surface of the mold must be smoothly slicked over with trowel and convenient slicks.

When this is done, paint on the facing wash with a very flexible long-bristled brush. Fig, 119 shows section of mold for a shrouded pinion, and illustrates points above mentioned. The runner is lead in at the bottom by use of a cover core, as described in dry-sand molding.

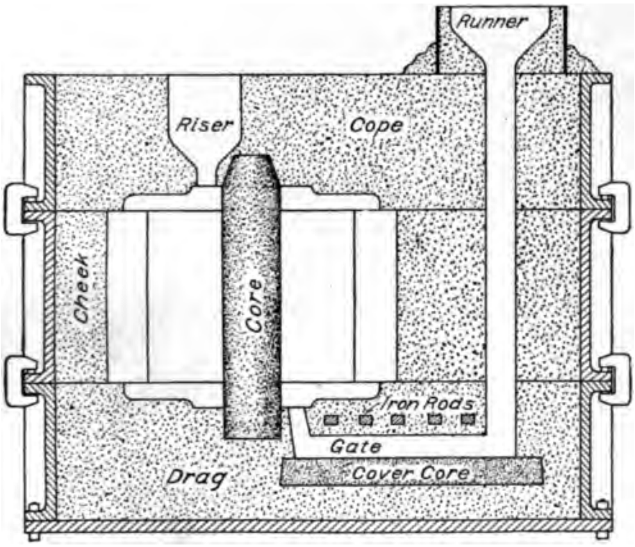


Fig. 119. Section Through Steel Mold.

Molds for steel should be more than dried; they should be thoroughly baked, to drive off every particle of moisture. This prevents the steel boiling in the mold and causing imperfections in the casting.

Where but little machine work is to be done on small work up to 1¼ inches thick, the molds may be made up in wooden flasks and poured green. For this class of work, only pure quartz sand and fire clay are used, tempered with molasses water. These may be made up and poured on the same day.

STEEL CORES

Where cores must be made in halves, one set of half-cores may be made and baked. The other half is then made and rolled over directly on the baked half. Fire clay wash is used to cement the joint. This method allows the joint between halves of core to be nicely slicked down.

Cores for steel molds are made up in boxes similar to those used in the iron foundry. Although using special sands, the cores are strengthened with iron rods, vented with cinders, and provided with convenient hangers for lifting, as described in previous paragraphs.

Steel cores must be more collapsible than those for iron, on account of the excessive shrinkage of the metal. This is provided for in the mixture of the sand used, and by thoroughly backing the core to reduce the effect of the binding materials to a minimum.

MELTING

The melting of steel is a science by itself, and cannot be dealt with adequately in a paper of this character. Only a very brief description of the process will be given.

The main feature is the difference in application of heat. Metal is melted in what is termed the *Open Hearth* furnace, a sectional plan of which is shown in Fig. 120. The charge of *scrap steel* and pig iron is placed on the central hearth. Heat is obtained by producer gas supplied with air-blast. Both gas and air are heated in one set of regenerators before entering the combustion chamber. The flame plays on top of the charge, and the waste gases pass off through

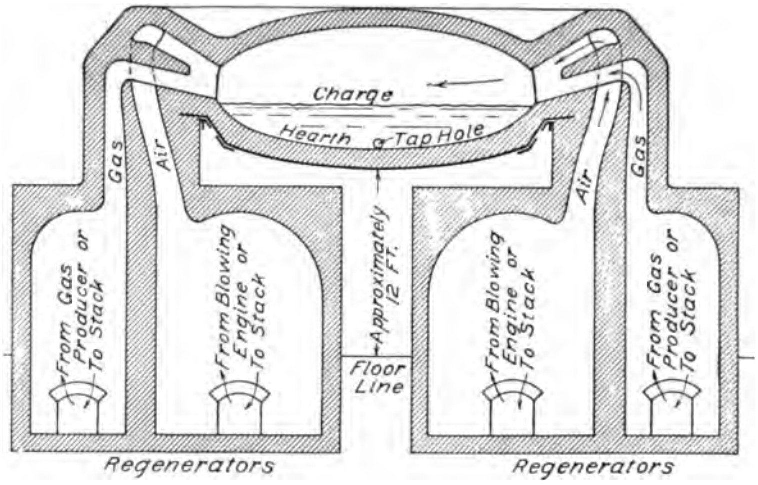

Charge
Hearth
Tap Hole
Gas
Air
Air
Gas
From Gas Producer or To Stack
From Blowing Engine or To Stack
Approximately 12 FT.
Floor Line
From Blowing Engine or To Stack
From Gas Producer or To Stack
Regenerators
Regenerators

Fig. 120. Section Through Open Hearth Furnace with Regenerators.

the other regenerator section of the furnace, heating up its brickwork. The direction of the gases is changed about every twenty minutes. The regenerator is practically a tunnel about 15 feet long, filled with brickwork built up as shown in Fig. 121. About 4 heats a day are run from the furnaces.

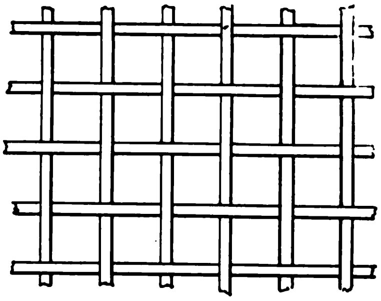


Fig. 121. How Brick is Set in Regenerator.

Samples of the bath are analyzed at intervals during the heat. Guided by these analyses the proper proportions of ores, fluxes, and pig are added to the bath to give it the right composition, a typical analysis of which has been given.

DRAWING THE HEAT

When the bath is in proper condition, the entire charge, be it 5 tons or 40 tons, is drawn off into a ladle previously heated by a special gas-burner. This ladle is lifted by the crane and carried to the pouring floor.

In order to secure the soundest metal free from pent gases or slag, all steel for casting purposes is tapped from the bottom of the ladle. The stopper is carried by a stiff round bar encased in fireclay tubing. This passes through the liquid metal (see Fig. 122), and may be raised or lowered by an arm attached to a rack-and-pinion mechanism bolted to the outer shell of the ladle and operated by means of a large hand wheel. The ladle is swung into position with tap-hole directly over pouring head. Four men hold the ladle steady with long iron rods. The metal thus enters the mold under the head of pressure of all the steel above it in the ladle.

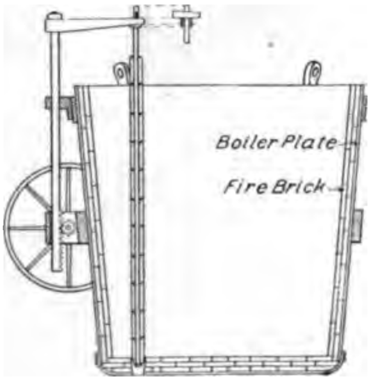


Fig. 122. Section Through Steel Ladle.

When all steel is drawn from ladle, the latter is swung on its side near furnaces, the stopper is removed, and all slag possible is racked out. The ladles must be repaired after each heat, often to the extent of replacing one-half of the thin fire-brick lining.

The casing of the stopper will last for but one heat, as the rod is sure to get bent out of shape. The rods are repaired by a blacksmith before recasing them.

SETTING UP STEEL MOLDS

This is usually done by a different set of men from those employed to make the molds.

For convenience in pouring, runner boxes (Fig. 123) are rammed up in small, round, sheet-metal boxes, using a wooden pattern to form the hole. These are baked in the oven.

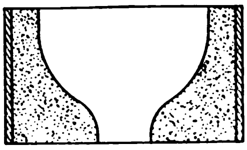


Fig. 123. Runner Box for Steel Mold.

When the molds are properly dried, they should be removed from the oven, placed on the pouring floor, and have the dust blown out with compressed air.

Now set the cores, close the mold, and clamp along joint flange. Set runner box over runner, and tuck heap sand around to prevent leakage.

This box serves simply as a funnel-shaped mouth to the runner. In pouring, the mold is filled only to the level of top of risers. The metal drains from the runner box, thus allowing it to be used more than once.

CLEANING STEEL CASTINGS

Steel castings do not run as smooth as cast-iron ones, but they have this advantage: If they show only slight surface defects, the metal may be peened over with a hammer to improve appearance.

The intense heat makes the metal burn into the sand greatly, so that cleaning is much more difficult. The sand often must be almost cut from the castings by means of long cold chisels, struck with sledges. Pneumatic hammers are used to a large extent in cleaning and in removing fins and slight projections. Where shrinkage webs will show, they must be cut out. Steel will not break off as does cast iron. The heavy gates and risers must be removed by metal saws (see Fig. 124) or by drilling a number of 1-inch holes side by side through the base of the riser and then breaking it off. The castings are generally annealed before the risers are cut off.

ANNEALING

In all steel castings of any size, cooling strains will develop on account of the shrinkage. These should be relieved by annealing. In suitable trench-like ovens, the steel is heated to a dull redness. This allows the grain to assume normal conditions. The heating is usually done with a wood fire. Overheating renders the grain coarse, and weakens the casting. Proper heat treatment materially increases strength and toughness, as indicated by the following figures:

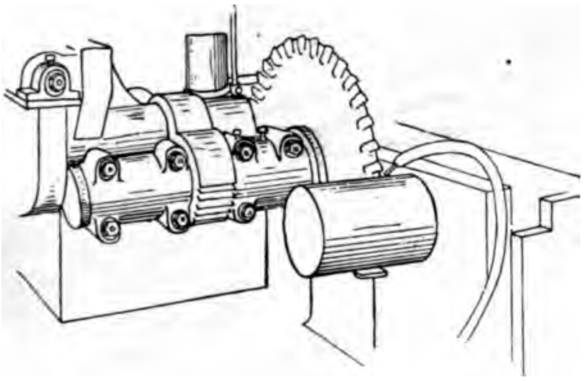


Fig. 124. Cutting off Riser.

	Tensile Strength	Elongation	Reduction of Area
Raw	80,360	13.31%	16.2%
Annealed	81,767	27.6 %	40.4%
Improperly annealed	79,421	14.3 %	17.8%

This shows that the work which is properly annealed is not only actually stronger, but is tougher and will stand more hard usage.

BRASS WORK

Cast iron and steel, which we have previously considered, are two forms of the same metal—iron. The difference in their physical characteristics is due solely to a variation in the proportions of certain elements or metaloids combined with the iron.

The metals to be dealt with in this section are termed *Alloys*—that is, mixtures of two or more separate metals.

The common alloys in use in the foundry for casting various machine parts are made from combinations of Copper, Tin, and Zinc, and are called *Brass* or *Bronze.*

Although the term Brass is held by some authorities to cover any of these combinations, the general classification accepts *Brass* as an alloy of *Copper* and *Zinc,* and *Bronze* as an alloy of *Copper* and *Tin.* In some sections the latter is spoken of as *Composition.*

Bronze has been used by man in all ages. Centuries before the Christian Era the Egyptians employed it for making coin, armor, and weapons, as well as household utensils, and statuettes of their gods. Analyses of many of these ancient relics show the composition to be almost identical with the bronzes of the present day. Brass also was in use before the time of Christ, but unquestionably bronze was of earlier origin.

A short discussion of the separate metals will help in understanding the properties of their alloys.

Copper has a red color; it is hard, ductile and very tough. It melts at about 2000° F., but it is difficult to make castings of the pure metal. Copper does not rust as does iron, and is one of the best conductors of heat and electricity. For this reason it is largely used in sheet form as a sheathing metal, and in the form of wire or rods, for electrical transmission. *Casting Copper* is put on the market in ingots of special form weighing from 18 to 25 pounds each.

Tin is a white lustrous metal, very malleable, but lacking tenacity. It may be reduced extremely thin by rolling, as is shown by tin foil. It melts at 450° F. When a bar of tin is bent it will give a crackling sound known as the "cry", which at once distinguishes it from other metals such as solder, lead, etc., which have similar external appearance. It is put on the market in pigs weighing about 30 pounds and also in bars of about 1 pound each. Its cost is approximately fifty per cent more than copper and five times as much as zinc. Tin may be cast unalloyed, and is sometimes used to run pattern letters or small duplicate patterns cast in zinc chill molds. The addition of one third to one half by weight of lead gives a cheaper metal, however, and one that will run equally well.

Tin mixed with copper gives greater fluidity, lower melting point, and greater strength, changing the color from red to bright yellow. Serviceable alloys may contain as high as 20 per cent tin. This gives a metal of golden yellow color, very hard, tough, and difficult to work.

With larger percentages of tin the color shades to gray, the metal is hard, brittle, and has little strength, and has no value for engineering purposes.

Zinc has a bluish white color; it is hard, but weak and brittle. The fracture shows very large crystals of characteristic shape. It melts at about 700° F., and shrinks but little in cooling. For this reason it may be used to cast directly for small metal patterns to form chills from which soft metal castings may be made for duplicating these patterns. If exposed to the air at high temperatures, zinc will "volatilize," that is, turn to a gas and burn. It burns with a bluish flame, and throws off clouds of dense white smoke. For this reason great care must be used to keep the air away from it as much as possible when being melted or mixed in an alloy, for aside from the loss of metal, an oxide is formed in the mixture which impairs the quality of the alloy.

Zinc is known in commerce under two names. When rolled into sheets it is called *Zinc*; when in ingot form for casting, it is called *Spelter*. These ingots are flat, approximately 8 x 17 x 1 inch thick, and weigh about 30 pounds. In this form they may be easily broken in small pieces for convenience in charging.

Zinc may be added to Copper in a very wide range of proportions, the alloy increasing in hardness and losing ductility with the increase in the proportion of zinc. The color changes from the red of the copper to a full yellow when one third zinc is used. Further additions of zinc change the color to red, yellow, violet, and gray. The alloys are serviceable up to 40 or 50 percent of zinc.

When Zinc is mixed with melted metal, considerable reaction or boiling takes place. This tends to make a more thorough mixture and to drive impurities to the surface. For this reason a small proportion, 2 to 3 per cent of zinc, is often stirred into bronze mixtures after the pot is drawn.

Lead has a bluish white color, and considerable lustre when freshly cut. It is malleable, soft and tough, but very weak. It melts at about 600° F.

Lead is not used by itself as an alloy with copper. A very small proportion may be added to the standard mixture for brass or bronze. It will cause them to run more fluid in pouring, and be softer for machining. For this reason lead is added to bearing mixtures to advantage. But it tends to deaden the color and reduce the conductivity of the metal for electrical purposes.

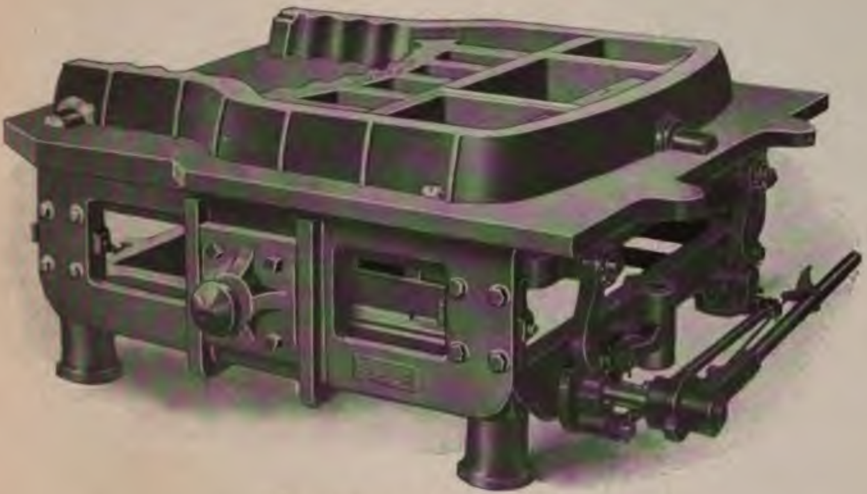
Proportion of Mixtures. The figures in the following table are given in percentages on one side for convenience in comparison and for figuring large heats. The beginner, however, will generally melt but one or two pigs of copper at one time. These he will weigh first and then figure the other portions of his mixture from this weight. In this case a formula given in pounds and ounces is much simpler.

Percentages				USE	Lbs.	Ozs.		
Copper	Tin	Zinc	Lead		Copper	Tin	Zinc	Lead
83.	12.	2.5	2.5	Gun metal for bearings. A very tough hard mixture.	1	2½	½	½
85	7.	5.	3.	Steam or Valve metal. Cuts freely, very tough, resists corrosion.	1	1¼	¾	½
90	5.	5.		Composition. For general use on small machine parts.	1	1	½	
90	6.	3.	1.	Bronze for Art work. Rich color, runs fluid at comparatively low heat.	1	1	½	¼
66.5	33.5			Common Yellow Brass. Good for general run of machine castings.	1		8	
66.	33.		1.	Same as above. Will machine a little easier.	1		8	½
1.80	64.70	33.35	1.	Anti Friction metal. For journal boxes.	1/16	32	16	½
	66.		34.	Good mixture for small patterns. Runs well, shrinks little.		2		1

From what has been said it will be understood that it is possible to vary these mixtures to meet special conditions. To harden or toughen an alloy increase the tin; to soften it reduce the tin. The same is true with zinc, but it will require larger proportionate changes in this metal to effect similar results in the alloy.

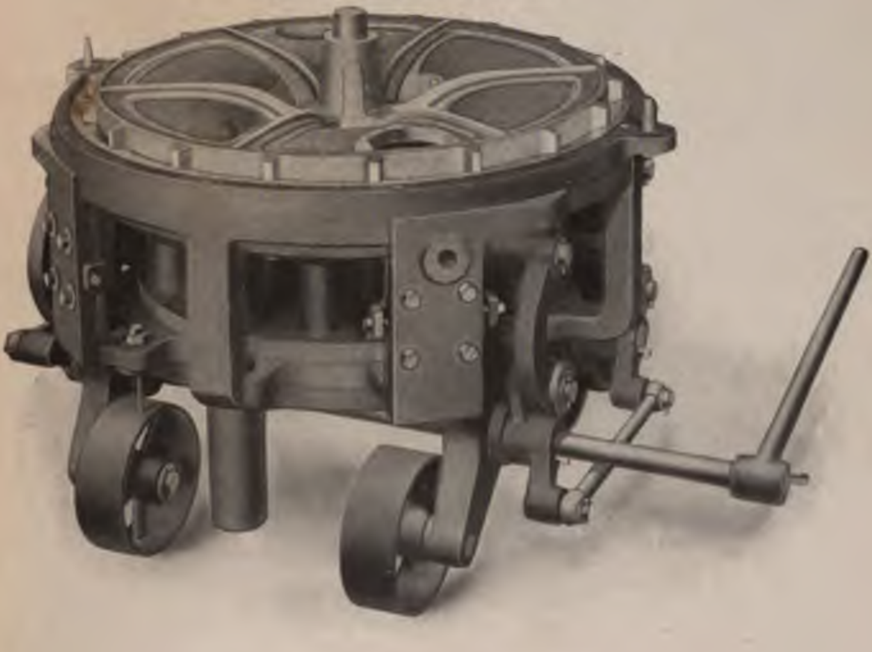
Phosphorus is not a metal, but is a very active chemical element manufactured from bone-ash. It has such an affinity for the oxygen of the air, that in its pure state it must be kept under water, because the slightest scratch would cause it to burn fiercely. It forms the principal substance used in making the heads of matches.

As a rule it is never used in the foundry in its pure state. For the production of *Phosphor Bronze* castings there are several combined forms of phosphorus on the market. The most convenient of these is known as *Phosphor Tin*. This is metallic tin carrying various fixed percentages of phosphorus of which 5 per cent is one very common



SQUARE MOULDING MACHINE

For Moulding Boiler Sections.



ROUND MOULDING MACHINE

For Making Wheels.

Henry E. Pridmore.

proportion. Knowing the amount of phosphorus carried by the tin, the exact proportion for the entire alloy may be readily calculated.

This element should not be used in alloys containing zinc or lead.

It acts as a flux, combining with any oxidized or burned impurities in the bath of metal and driving them to the top. It tends to make the tin crystalline in form, in which condition it unites more firmly with the copper. It apparently unites chemically with copper, making that metal harder. The proportion of phosphorus should not exceed .75 per cent, while .25 to .40 per cent are safer proportions.

Two typical mixtures, using 5 per cent phosphor tin, are as follows:

PHOSPHOR BRONZE MIXTURES

For a Tough Alloy	For a Hard Alloy		For a Tough Alloy	For a Hard Alloy
90. %	87.50 %	Copper	9 lbs.	8¾ lbs.
9.75	12.25	Tin	½ lb.	¾ lb.
.25	.25	Phosphorus		
		Phosphor Tin	½ lb.	½ lb.
100	100.	Totals	10 lbs.	10 lbs.

MATERIALS

Natural molding sands are used for brass-work. They are usually finer than sands used in iron-work, because brass parts are generally small and often have fine detail which must be brought out very sharp in the mold. For this reason also the sands should have more alumina or bond than iron sands.

This increase of bond is possible because the metals entering the mold are not as hot as iron, therefore do not require as much vent, but they have a greater tendency to "cut" the mold.

For the general run of work the whole heap is kept in good condition by the frequent addition of new sand, but on large work a facing mixture is used similar to the Iron Foundry.

Burnt sand, powdered charcoal and partimol are all *good parting materials*. The last two are best on small work, as they make a cleaner joint. They are not blown off of the patterns, because they make a good facing for the mold.

The brass molder uses practically the same kinds of tools, such as shovels, sieves, rammers, and molder's tools general described.

Snap Flasks may be used, but the pins, hinges an be kept in careful adjustment so that the parts of the mol

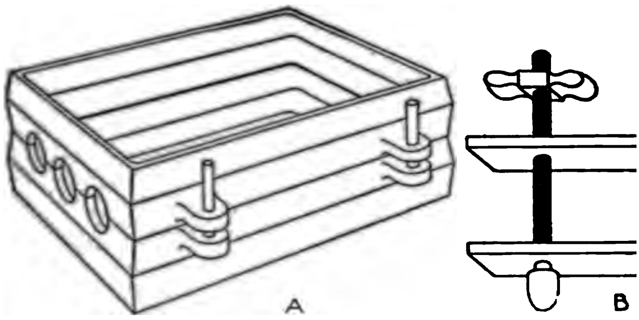


Fig. 125. (A) Flask for Brass.—(B) Screw Clamp.

perfectly. The same is true of the larger box flasks f

The most typical *brass flasks* are of cast iron w fitting round steel pins. See Fig. 125 A. They hav joint at one end of the flask so that the mold may be set pouring.

This gives a decided additional pouring pressure wi thickness of sand over the castings.

Boards without cleats support the sand in the flask

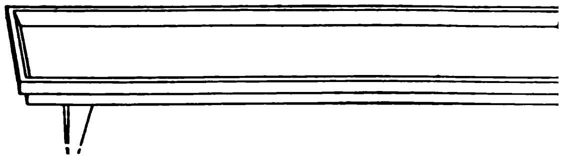


Fig. 126. Spill Trough.

is clamped before setting on end by means of some f screw clamp similar to the illustration, Fig. 125, B.

Great care is taken in the brass shop to save all sl metal possible. To this end, when the molds are to be they are leaned against a cast iron *Spill trough* show There should be a 1-inch layer of sand over the botto The crucible is held over it when pouring the molds, t possible to conveniently catch any metal that is spilled.

For thin work the face of the molds are *skin dried* t moisture before the metal enters the mold. *Drying stoves* similar to Fig. 127, are used for this purpose. When the mold is finished the two halves are carefully sprayed with a weak molasses water, and the flasks set on end on the wide platform with the face of the mold next the stove. When sufficiently dry the mold is closed and poured at once.

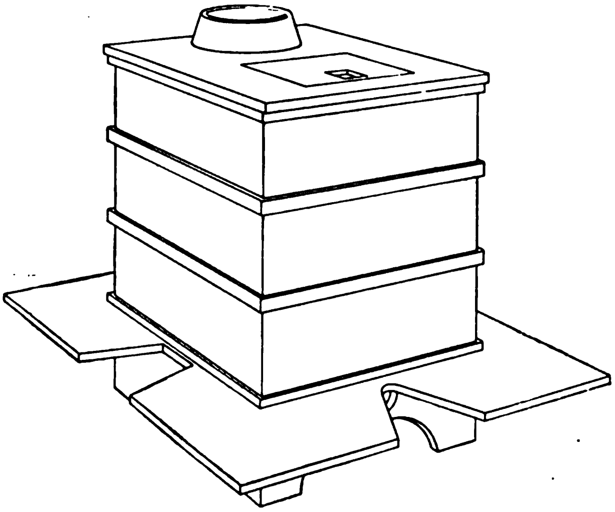


Fig. 127. Drying Stove.

PRINCIPLES OF THE WORK

Brass work deals as a rule with smaller quantities in every way than does iron work. The patterns are generally smaller and the brass molder takes particular pride in making all his joints so neat that hardly a fin will show on his castings. The matter of catching the shot metal has been mentioned. Up to the introduction of the oil-melting furnace it was customary to heat a pot of metal for each molder. These heats were comparatively small, so that he would make up possibly six or eight molds, then draw his pot and pour them; running in this way several heats in a day.

Using the furnace, several heats are run each day, but a much larger quantity of metal is melted at each heat, so that the work of several molders is poured with exactly the same metal.

A mold for brass should be rammed about the same as for iron. On name plates and thin work, after the initial facing of sifted sand has been properly tucked with the fingers, the flask is filled heaping full of sand. Then by the aid of a rope hanging down from the ceiling, the molder springs up on top and packs the mold with his feet, the weight of his body giving the right degree of firmness to the sand. Stove-plate molders often pack their flasks in the same way.

The main difference between making up molds for brass and those for iron are due to three causes: Brass melts at a lower heat; it does not run as fluid as iron; it has about double the shrinkage of iron.

For these reasons the sand may be somewhat less porous and still vent sufficiently, if risers are placed to allow for the escape of the air. On bench work the vent wire is not used.

The runners for brass should be larger than for iron, and the gates, instead of being broad and shallow, should be more semicircular in section. Pouring molds on end gives the pressure necessary to force a more sluggish metal to take a sharp impression, and the heavy runners shown in the following examples serve to feed the casting as it shrinks.

Forms of skimming gates, as explained in an early section, are used to advantage on work of a very particular nature.

EXAMPLES OF WORK

To illustrate more clearly some of the typical methods of brass work, let our first example be a thin flat plate with decoration in low relief on one side.

Place the pattern face down, a little below the center of flask. Sift on facing through a No. 16 sieve, then tuck, fill and pack as previously described. Roll over and make a joint. Now cut a half section of the main runners and risers, but do not connect them with the mold at this stage. Dust on parting material from a bag, and ram the other half of flask just hard enough to stand handling. Separate flask; spray face of mold with weak molasses water, and dust on it from a bag some finely powdered pumice stone, or any fine strong sand, and over this a little parting dust. Now replace this half over the pattern and re-ram to the required firmness and again separate and this time draw the pattern.

The impression of the runners and risers cut in the first half of the mold will show as ridges on the second half packed, and serve as guides for cutting the runners to a full round section. Connect the gates in four places, as shown in Fig. 128 A. Skin dry the mold and it will be ready to close and pour.

Dusting fine sand on the face of the mold then reprinting, as it is termed, ensures a very smooth, perfect mold face. Where the mold is not skin dried, *flour* is dusted over the face, allowed to stand for a short time, and then blown off. This makes a good facing.

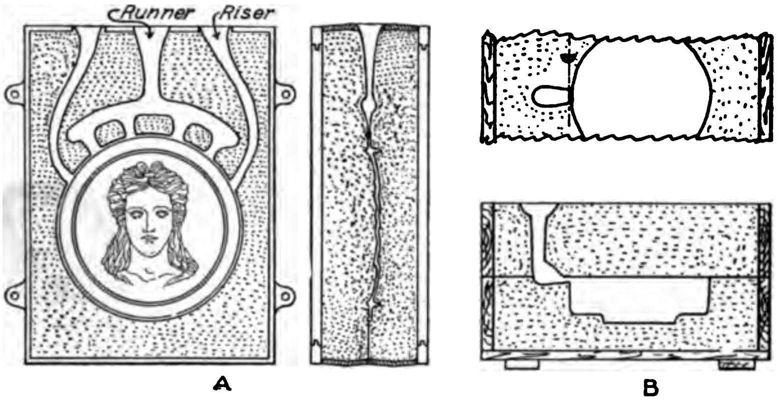


Fig. 128. (A) Mold for Thin Plate.—(B) Mold for Heavy Plate.

Cutting the heavy runner over the top of the thin plate ensures a sufficient supply of clean hot metal to the gates under pressure enough to force the metal into every detail of the mold before it has time to chill.

B, Fig. 128, shows the difference in construction of gate when a heavier piece is cast with the flask setting horizontally. The gate proper is cut in the drag, but a good feeding head is cut out of the cope side to keep the metal in the riser liquid until the casting has solidified.

For duplicating work the sand match, oil match, or follow board are used, the same as for iron work.

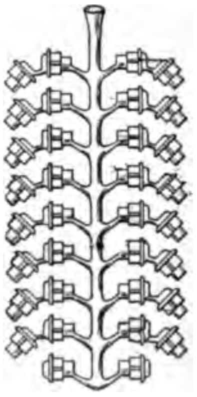


Fig. 129. Duplicate Gated Work.

Fig. 129 shows a typical set of castings run from the end and made from gated patterns set in an oil match. Steady pins are placed on the gates to facilitate a clean lift.

Cores for brass work are made up as previously described. To give a smoother surface on the small cores about one third molding sand is often mixed in with the beach sand of the stock mixture.

CLEANING

When the castings are taken from the sand they should be rapped smartly to free all loose sand, then, if machining is to be done on them, they should be plunged, while hot, into water. This softens the castings. This method is used also to *blow out* cores from small work.

A Sprue Cutter, shown in Fig. 130, is part of the equipment of a brass foundry. These machines are made to operate by foot as shown or by power. With them the castings are cut neatly and quickly from the runners.

Brass does not burn into the sand as much as iron, therefore, in many shops, the small castings are brushed clean before being cut from the gates, by means of a *circular scratch brush* mounted on a spindle similar to a polishing wheel.

A good method of cleaning brass and bronze is by *pickling.* Make a mixture of 2 parts common nitric acid and 1 part sulphuric acid, in a stone jar. Place the piece to be cleaned in a stone *dipping basket,* Fig. 131, and dip once into the acid, then wash off in clean water and dry in sawdust.

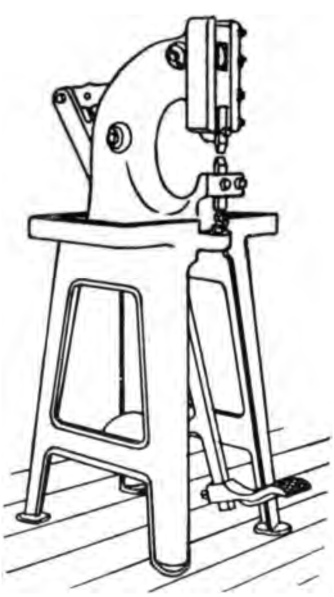


Fig. 130. Sprue Cutter.

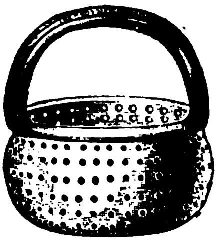


Fig. 131. Dipping Basket.

In many cases brass chips and filings will be turned back to the foundry to be remelted. The smallest portions of steel or iron in these would prevent their being used in this way, as they make extremely hard spots in the castings.

Fig. 132 shows a *magnetic separator* which effectively removes all steel and iron chips. The brass chips and sweepings from the machine shop are placed in the hopper of this machine. They are caused to be spread out on one side of a slowly revolving brass covered drum, A. Inside of this brass shell are strong magnets which hold the steel and iron chips to the surface while the brass chips drop off into a tote box. A stiff brush at the back of the cylinder removes the iron chips and they drop into a separate box.

MELTING

All alloy metals burn if exposed to the air while melting, and especially zinc and tin. To prevent this burning the brass melter endeavors to control the draft in his furnace so that all oxygen entering the gates will combine with the fuel, so that gases which may reach the metal shall contain no free oxygen.

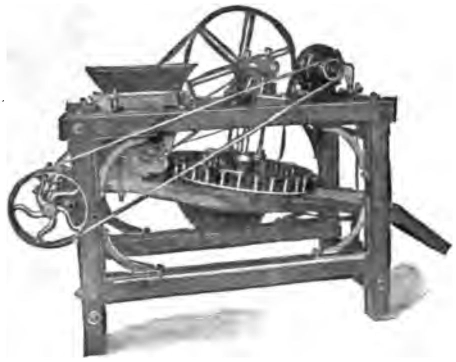


Fig. 132. Magnetic Separator.

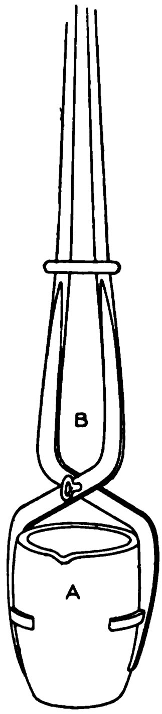


Fig. 133. (A) Crucible. (B) Tongs.

For this reason the ordinary brass furnace is a natural-draft furnace, although a forced draft is often connected below the grates to make combustion independent of atmospheric conditions.

The metal does not come in direct contact with the fuel, but is contained in fire-clay pots called crucibles, which are bedded in the fire. Hard coal or coke is used for fuel.

These *crucibles*, Fig. 133, A, are manufactured from a very refractory fire-clay mixture and are strong and tough even at a high temperature. They are lifted in and out of the furnace by the tongs shown at B, Fig. 133. For the larger sizes a crane is used for hoisting the pot.

Crucibles are made in a great variety of sizes, as they are used in many different metal industries, from that of the jeweler to that of the steel manufacturer. They are classed by number, the following table gives data regarding a few sizes.

SIZES OF CRUCIBLES

Nos.	Holding Capacity Liquid Measure			Height Outside	Diameter at Top Outside	Diameter at Bilge Outside	Diameter at Bottom Outside	Capacity in Weight of Water
	Gal.	Qt.	Pt.	Inches	Inches	Inches	Inches	
0				2	1½	1⅝	1¼	
0000				3	2⅜	2½	1¾	
6		1		6½	5¼	5⅛	3¾	2.08
12		2		8	6¼	6¾	5	4.16
30	1	1	1	11	8⅝	9¼	6½	11.5
60	3			14	10⅜	11⅝	8	25.
90	4			15⅞	11½	12½	9	33.3
300	12	2		22	16¼	17½	12½	104.

The melting capacity of any of these sizes may be obtained by multiplying the figure given in the column "Weight of Water" by the specific gravity of metal to be used.

New crucibles should always be *annealed* before using, that is, brought very slowly to a low red heat. This drives out any moisture absorbed from the air since coming from the kiln in which they were baked. Disregard of this generally results in a cracked crucible.

Natural Draft Furnaces are usually called brass furnaces, and may be bought on the market made up in single complete units.

Fig. 134 illustrates one of a battery of several furnaces connecting with a common flue. The top is on a level with the molding floor. The sketch shows clearly the principles of construction. A cast iron bottom, plate A, with a circular opening, carries a shell of boiler plate lined with fire brick. The diameter of the inside lining should be 6 inches larger than the crucible to be used. A top plate, with a similar opening, binds the whole together. On one side, below the top, an opening, B, which may be formed by a cast iron box, connects with the flue or stack. Two heavy ribs, cast on the bottom plate, rest on a pair of rails as shown, and these rails are supported by suitable piers of brickwork, about two feet high, so that ashes may be conveniently removed when the furnace is dumped. In the space between the bottom plate and rails, made by the ribs, the grate bars, C, are set. These bars are loose and may be pulled out when it is desired to dump the fire for the day.

Operation. In running off a heat a bed of freshly lighted fuel about 8 inches deep is made over the grate bars. The crucible, packed as full as possible with the charge, is lowered in and the space around it filled with fuel. The crucible should be kept covered, especially for brass. In melting brass, melt down the copper first, then the scrap. When this is melted, charge the zinc and stir well before lifting the pot. Allow the mixture to come to the proper heat again, then pull the pot, skim off the dross, and stir in the lead if any is called for, just before pouring.

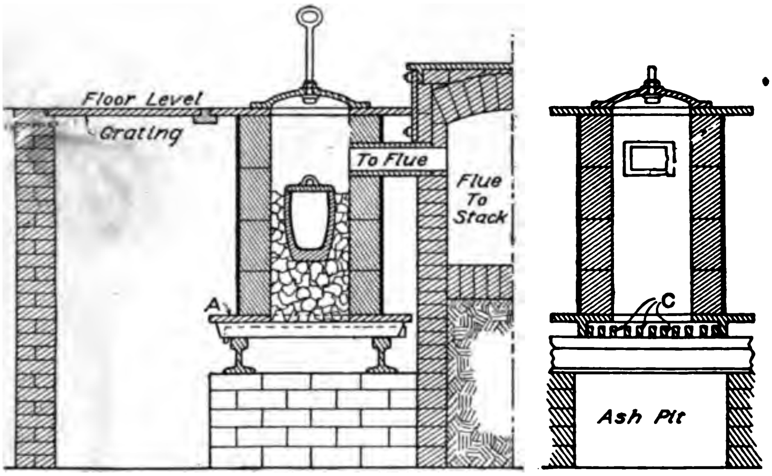


Fig. 134. Natural Draft Furnace.

In bronze the same method is pursued, but both the tin and zinc are stirred in after the pot is drawn.

In mixing in the zinc in brass, care must be taken to plunge it well under the surface of the copper with long handled pick-up tongs, and to hold the piece down with the stirring bar until it has melted.

Where a large casting requires more metal than can be melted in a single crucible, several furnaces must be used and the contents of their various crucibles assembled into one large pouring ladle just before pouring.

Gas or Oil Furnace. With the development of natural gas and crude oil burners for commercial heating, several good furnaces have been designed in which a large quantity of metal can be melted at one time.

Fig. 135 shows a furnace of this character in section. This type has tandem melting chambers with burners at the end, which may be used separately or both together. The waste gases from the bath of liquid metal are used to heat up a fresh charge in the other chamber.

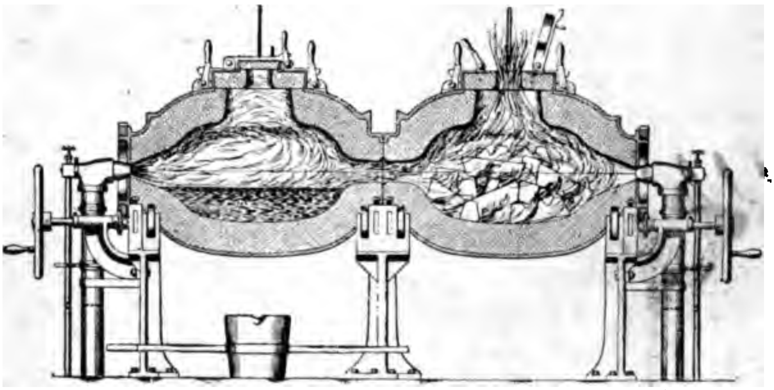


Fig. 135. Section Through Oil Furnace.

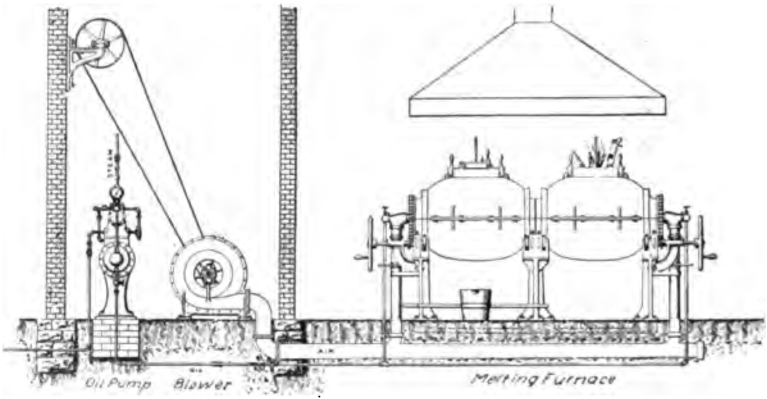


Fig. 136. Oil Furnace - General Elevation.

The metal is charged and poured from the openings at the top of the furnace. Each chamber may be revolved separately, to empty the furnace when the charge is melted. Fig. 136 shows the general arrangement of the oil feed pump, and blower for these melting furnaces.

The flame plays directly on to the metal. The oil pressure should remain constant at about 5 pounds per square inch. But the air pressure is regulated to vary the intensity of the heat as desired.

The pouring ladle must be well heated before using. This is done with a special gas burner, or when crucibles are used, they are often heated by means of a small fire in an ordinary furnace.

Different sizes of furnaces are built to melt from 250 to 2000 pounds of metal at a heat. Twelve or fourteen heats a day can be run. The saving is approximately 50 per cent in time and is also very considerable in expense, over ordinary crucible furnaces of equal capacity.

SHOP MANAGEMENT

The success of a foundry depends upon the ability of its managers to promptly turn out castings which will meet the requirements demanded of them, at the lowest possible cost commensurate with the quality of the work. In this chapter we wish to direct the attention of students to some features in the way of equipment and management which aid in accomplishing these results.

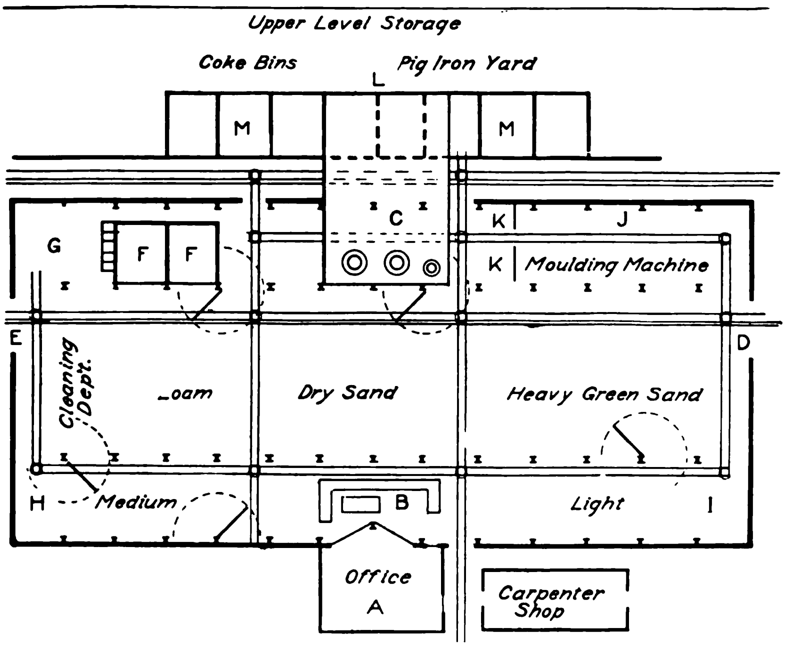


Fig. 137. Typical Plan of Foundry.

The most important processes in the foundry are melting metal, making molds, and pouring them. Much of the work necessary in preparing for these processes consists of handling heavy materials such as coke, iron, sand, etc. To reduce this handling to its lowest limits, as to distances, number of re-handlings, and methods of conveyance, are problems to be considered in the plan of the shop as a whole.

To briefly illustrate some of the points to be brought out, let us consider the plan of a shop shown in Fig. 137, and its sectional elevation shown in Fig. 138.

The building is of steel construction and the columns supporting the roof trusses serve also to carry the tracks for the overhead traveling cranes.

The outer walls should be filled in with some good weather-resisting material of which there is nothing better than brick. These walls should be of good height and have a sufficient window area to supply light well in toward the middle of the shop.

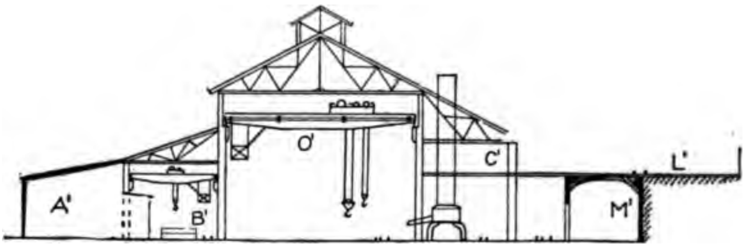


Fig. 138. Typical Elevation of Foundry.

The method of heating and ventilation best adapted for a foundry is the indirect fan system. One or more large fans situated generally toward the ends of the shop, draw fresh air in through a compact system of steam coils, and by means of overhead piping deliver it to all portions of the shop. The impure gases are carried off through ventilators in the clear story at the top of the roof.

The floor of the foundry should consist of molding sand, the depth of the sand floor varying with the class of work to be done. If the natural soil of the grounds is open and porous, a thickness of 3 or 4 inches of clay well rolled down should be put in underneath the sand floor. This will help greatly in keeping the molding floor in good condition, as it prevents the moisture draining out of the sand.

The foundry office should be located at such a point that the foreman can command a view of the whole shop. It should be convenient to the different departments and at the same time be protected as far as possible from dust. The office room, shown in Fig. 137 at A, is built on the outside of the main building, but has a large bay window which projects a few feet into the shop from which all corners of the foundry can be seen.

A space B having suitable low tables and shelving, is reserved near the office for the temporary storing of patterns in daily use. This brings them directly under the attention of the foreman and his assistants who can readily check the patterns as they come in and quickly find those requiring prompt attention.

At C is shown the cupolas, directly opposite the foreman's office, and so situated that all of the molding floors may be served as quickly as possible without interfering one with the other.

In large foundries there are two or more cupolas, to admit of different mixtures being melted simultaneously. Often a comparatively small cupola is installed near the floor for light work for the service of that floor alone.

The blowers should be placed near the cupolas avoiding long connecting wind pipes. The application of electric motors removes the necessity of concentrating the power at one point in the shop.

The main bay of the foundry is devoted to the heaviest work and is served by at least two overhead cranes.

The heavy green sand castings are made at one end so that the flasks for this work may be stored in yards near by and be brought in through the door D. These molds are made up furthest from the cleaning shed because only the castings themselves need be transferred there.

The flasks and rigging for the dry sand and loam molds should be brought in through the opposite door, E. The loam work as a rule is the most bulky to handle and should be nearest the cleaning sheds so that it need not be carried across the other floors. Both dry sand and loam floors are convenient to the large ovens, F.

The core shop is situated in the side bay at G, to make it convenient to swing the large cores on to the buggies to be run into the large ovens. A jib crane near the corner of these ovens makes the men working on such cores independent of the traveling crane. The ovens for small cores are built along the side of the large ovens and utilize the same stoke hole, ash-pit and stack.

Distributed through the side bays also are the medium work floor H the light work floor I and the molding machine floor J. This ensures a supply of good light necessary to the smaller details of this class of work.

The molding machines are placed on that side of the shop near the sand storage sheds, to allow for handling the sand by means of belt conveyors, with hoppers above the machines, an illustration of which is shown in Fig. 139.

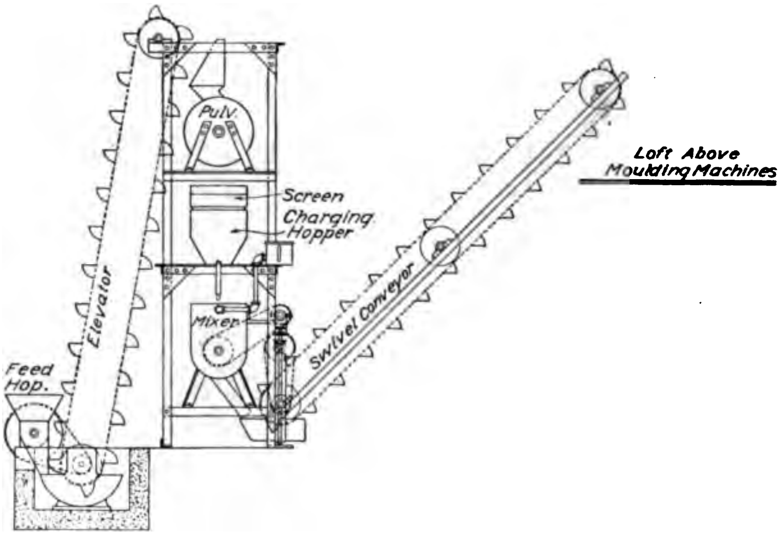


Fig. 139. Automatic Sand Mixer.

The sand-mixing space is in the side bay near the cupolas at K, and is furnished with power from independent motors or from a jack shaft leading from the blower room. This position affords direct access to the sand bins. The raw material after being mixed and tempered is delivered by barrow or sand car direct to the various floors. The mixers might be installed in one of the storage vaults across the roadway.

The quickest means of unloading either wagon or carload lots of material is by dumping, where the material can be so handled. One of two things is necessary to accomplish this: either the storage bins must be placed in a basement underneath the roadbed, or the roadway must be run up an incline over the top of the bins. The former method is more frequently met with in the crowded condition of the large cities, but the latter is preferable because less time is consumed in running material up an incline in large quantities than will be required to hoist small quantities more frequently from a basement.

At L and L′, Figs. 137-138, is shown the storage yards for pig iron and coke; these are on a level with the charging platform of the cupola C C′, and can be loaded on cars and pushed directly to the charging door. In some modern shops these push cars are built so that their load may be dumped as a whole into the cupola.

The storage for core oven fuel, sands and clay, is shown at M M, in bins built underneath the tracks and on a level with the foundry floor. These bins should be arranged to open on top with a shute under the track and a trap at the side so that coal or sand may either be dumped or shoveled directly into them.

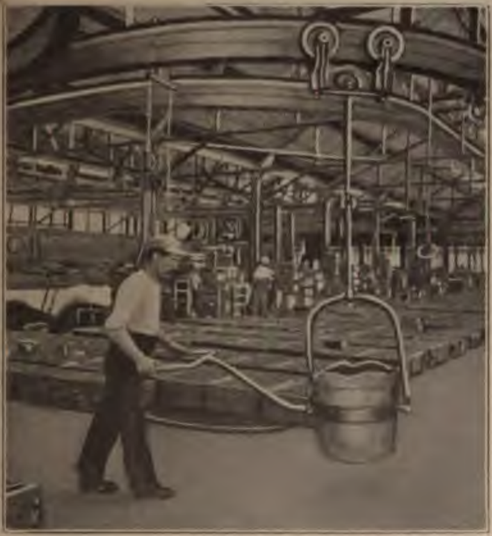


Fig. 140. Overhead Track and Trolley.

In the largest shops a standard gauge track should run directly through the main foundry, also similar tracks through the roadway next the cupola bay, for convenience in removing the dump. The track over the storage bins has been mentioned.

Two methods of transferring material between departments within the shop, aside from the cranes, are the overhead trolley system, Fig.

140, and the narrow gauge industrial railway. The former is of advantage in manufacturing plants where the loads to be transferred are nearly uniform in weight and frequency of handling. This system leaves gangways smooth and free from obstructions. For general work, however, the industrial railways are more frequently installed. These serve all floors to deliver flasks, sand, or iron, and to remove castings.

Of the many styles of overhead traveling cranes that are on the market those using electricity as the motive power are undoubtedly the most serviceable. The cranes in the main foundry indicated at O′, Fig. 138, should have two hoisting drums on the carriage; one for such light work as handling flasks, rigging and patterns, the other for the heavy work on the large ladles and castings.

Small jib cranes furnished with a 2- to 4-ton air or electric hoist placed on the side of a man's floor make it possible for the molder and helper to handle work of considerable size by themselves, and prevent loss of time waiting on the overhead crane.

The method of distributing the melted metal varies with the class of work made. In shops doing general jobbing work, the ladles for pouring the largest work are carried from the cupola direct by the overhead cranes.

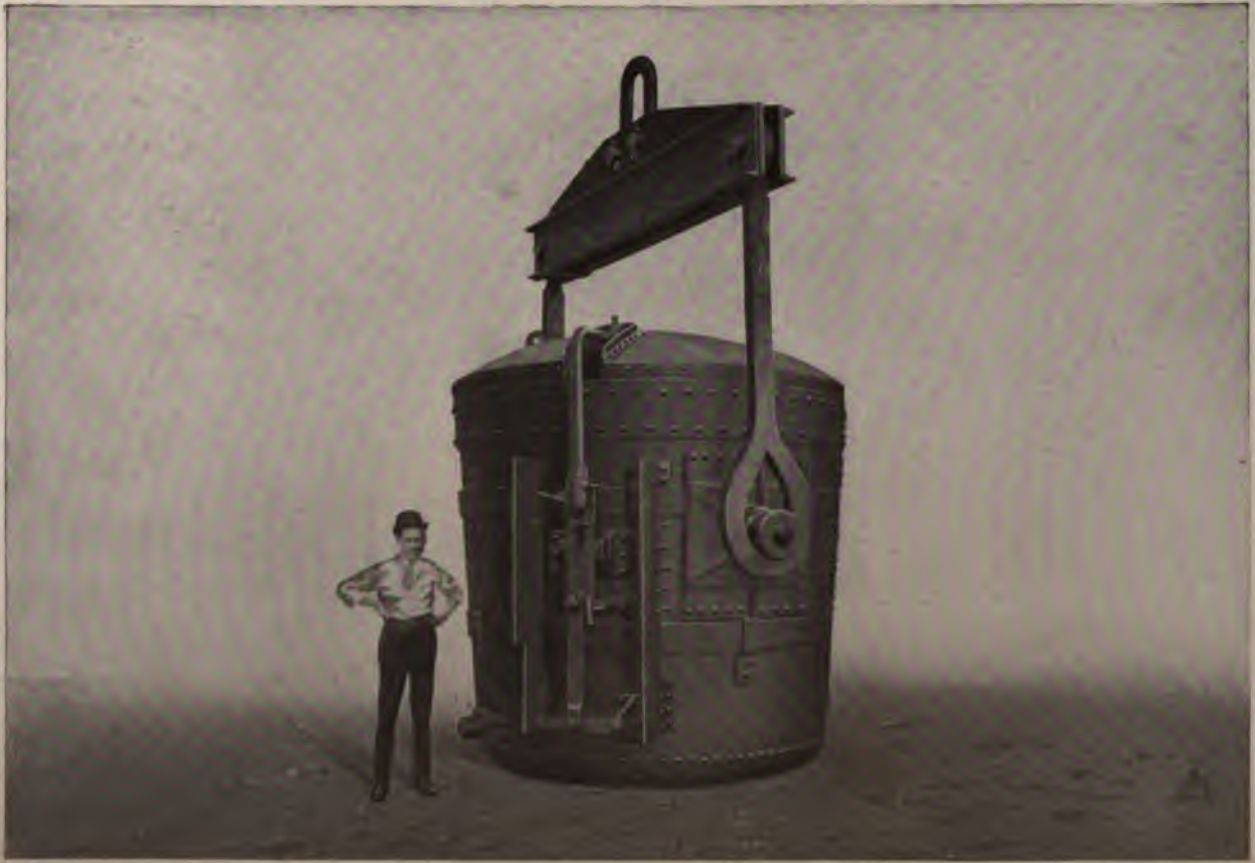
For serving the floors in the bays one of the systems mentioned above is generally used. The metal is conveyed to the floor in a large ladle and from this smaller ones are filled and carried by hand or by a small crane to the molds.

The cleaning department should be situated at one end of the shop near E, Fig. 137, or in a shed extension to the foundry proper. It requires space to pile the castings as they are brought from the floors with sufficient room for the men to begin work on these piles. As a rule the smaller castings are first collected and put through the tumbling barrels, then the medium work is cleaned by hand or sand blast; this leaves room for work around the largest pieces. As soon as castings are cleaned they are weighed and shipped to the customer, store house, or to the department which does the next operation upon them.

DIVISION OF LABOR

The division of labor in a foundry is briefly as follows:

The superintendent is responsible for the operation of the foundry



50-TON LADLE.

The William B. Pollock Co.

as a whole. He hires the men and oversees the purchase of materials and supplies, having under him clerks who keep track of the details of this work. Some of the things to which he gives personal attention are:

In consultation with his foreman he gives personal attention to the receipt of the most important patterns; decides how they shall be molded; on what floor and what mixture shall be used to pour them. He devises ways and means of increasing the productiveness of his shop.

The foreman or his assistants must be in the shop a sufficient time before work begins for the day to see that each molder has work laid out for him, and must keep the men supplied with work through the day. He estimates the amount of the charge for the day and directs the melter as to mixtures.

It is the duty of the foreman and his assistants to give directions to the apprentice boys and to see that these directions are carried out to the best of the boys' ability.

The molders should give their entire time to making up molds. On floor work they are usually given a helper who totes flasks, cores, chaplets, etc., and does the heavier work when handling the sand. When the molds are poured and his flasks stripped off the molder is through for the day.

Most modern shops employ a night gang of laborers to put the shop in proper shape for the molders to start their special work immediately when the whistle blows in the morning. These men remove the castings from the sand and transfer them to the cleaning shed. They pick out all bars and gaggers used in the molds and stow them in place. They temper and cut the sand and dig away pits necessary for bedding in work.

CHECKING RESULTS

The methods of mixing iron by analysis have been dealt with in an earlier chapter, but these mixtures must be checked by physical tests on the resulting castings.

Two systems are now in more or less general use throughout the United States.

Mr. W. J. Keep, of Detroit, Michigan, who has had long experience in this subject, has invented a very complete system of regulating mixtures which he terms "Mechanical Analysis." Fig. 141 A shows a follow board arranged with patterns and yokes. The test bars are ½ inch square and 12 inches long. They are cast in green sand with their ends chilled against the faces of the cast iron yokes, shown in the cut. Three molds should be cast each heat, and the test bars allowed to cool in the molds.

Mechanical Analysis is based on the fact that silicon is the most important variable chemical element in cast iron, and that shrinkage in castings is directly proportionate to the silicon in the mixture.

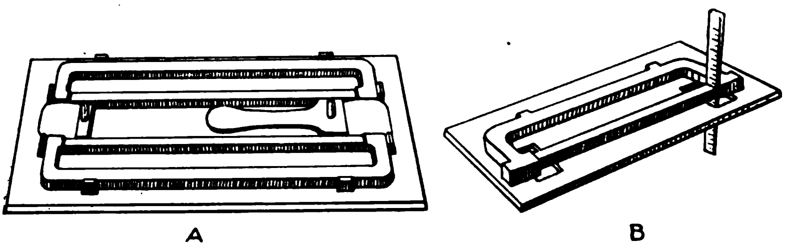


Fig. 141. (A) Keep's Test Bar Pattern.—(B) Measuring Shrinkage.

The first test is to replace each bar in the same yoke in which it was cast and by means of a specially graduated taper scale ascertain accurately the amount of shrinkage. See Fig. 141, B.

The shrinkage of the bars when the castings prove satisfactory should be considered the standard for that class of work for that shop. If at any time the shrinkage is greater than the standard, increase the silicon by using more soft pig; if it is less, decrease silicon by using more scrap or cheaper iron.

The depth of chill on the castings is measured after chipping off a piece from the end of the bar.

The third test is to obtain the transverse strength of each bar. This is done on a special testing machine which gives a graphical record of the deflection and ultimate breaking load. These dead loads will vary with different mixtures approximately from 340 to 500 pounds.

Quoting from Mr. Keep's circular:

"With high shrinkage and high strength of a ½-inch square test bar, heavy castings will be strong but small castings may be brittle.

"With low shrinkage and high strength large castings will be weak and small castings will be strong.

"With uniform shrinkage an increase in the strength of a ½-inch square test bar will increase the strength of all castings proportionately."

The other form of tests was devised by a committee of the American Foundrymen's Association, and is recommended in the Proposed Standard Specifications for Gray Iron Castings by the American Society for Testing Materials. A partial summary of these specifications is as follows:

> "Unless furnace iron is specified, all gray castings are understood to be made by the cupola process.
>
> "Light castings are those having any section less than ½ inch.
>
> "Heavy castings have no section less than 2 inches.
>
> "Medium castings are those not included in the above"

The test bar is 1¼ inches in diameter and 15 inches long, and is known as the "Arbitration Bar." The tensile test is not recommended but if called for a special threaded test piece is turned down from the "Arbitration Bar," and has a test section .8 inch in diameter and 1 inch between shoulders.

The transverse test is made with supports 12 inches apart.

Fig. 142 shows a sketch of the patterns for these bars. Two bars are rammed in a flask and poured on end. The small prints on the two bar patterns project into the cope and are connected by one pouring basin. A special green sand mixture is specified for making these molds; the molds are to be baked before pouring, and the bars allowed to remain in the sand until cold.

The following table shows the specified requirements:

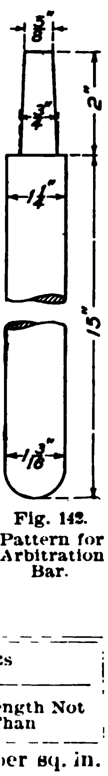


Fig. 142.
Pattern for Arbitration Bar.

TESTS ON "ARBITRATION BAR"

Grade of Castings	Chemical Properties	Physical Properties	
	Sulphur Content Not Over	Transverse Test* Minimum Breaking Strength	Tensile Strength Not Less Than
Light castings	0.08 per cent	2500 lbs.	18,000 lbs. per sq. in.
Medium castings	0.10 per cent	2900 lbs.	21,000 lbs. per sq. in.
Heavy castings	0.12 per cent	3300 lbs.	24,000 lbs. per sq in

*In no case shall the deflection be under .10 of an inch

RULES AND TABLES

MENSURATION

Circumference of a circle = diameter × 3.1416
Area of a square or rectangle = base side × height
Area of a triangle = base × perpendicular height
Area of a circle = diameter squared × .7854
Convex surface of a cylinder = circumference × height
Convex surface of a sphere = circumference × diameter
Contents of a rectangular solid = area of base × height
Contents of a cylinder = area of base circle × height
Contents of a sphere = cube of diameter × .5623
One side of square having same area as given circle = diameter × .8862 or circumference × .2821

AREAS OF CIRCLES AND THEIR CIRCUMFERENCES

Diameter	Area	Circumference	Diameter	Area	Circumference	Diameter	Area	Circumference	Diameter	Area	Circumference
⅛	0.0123	.3926	10	78.54	31.41	30	706.86	94.24	65	3318.3	204.2
¼	0.0491	.7854	½	86.59	32.98	31	754.76	97.38	66	3421.2	207.3
⅜	0.1104	1.178	11	95.03	34.55	32	804.24	100.5	67	3525.6	210.4
½	0.1963	1.570	½	103.86	36.12	33	855.30	103.6	68	3631.6	213.6
⅝	0.3067	1.963	12	113.09	37.69	34	907.92	106.8	69	3739.2	216.7
¾	0.4417	2.356	½	122.71	39.27	35	962.11	109.9	70	3848.4	219.9
⅞	0.6013	2.748	13	132.73	40.85	36	1017.8	113.0	71	3959.2	223.0
1	0.7854	3.141	½	143.13	42.41	37	1075.2	116.2	72	4071.5	226.1
⅛	0.9940	3.534	14	153.93	43.98	38	1134.1	119.3	73	4185.3	229.3
¼	1.227	3.927	½	165.13	45.55	39	1194.5	122.5	74	4300.8	232.4
⅜	1.484	4.319	15	176.71	47.12	40	1256.6	125.6	75	4417.8	235.6
½	1.767	4.713	½	188.69	48.69	41	1320.2	128.8	76	4536.4	238.7
⅝	2.078	5.105	16	201.06	50.26	42	1385.4	131.9	77	4656.0	241.9
¾	2.405	5.497	½	213.82	51.83	43	1452.2	135.0	78	4778.3	245.0
⅞	2.761	5.890	17	226.98	53.40	44	1520.5	138.2	79	4901.6	248.1
2	3.141	6.283	½	240.52	54.97	45	1590.4	141.3	80	5026.5	251.3
¼	3.976	7.068	18	254.46	56.54	46	1661.9	144.5	81	5153.0	254.4
½	4.908	7.854	½	268.80	58.11	47	1734.9	147.6	82	5281.0	257.6
¾	5.939	8.639	19	283.52	59.69	48	1809.5	150.7	83	5410.6	260.7
3	7.068	9.424	½	298.64	61.26	49	1885.7	153.9	84	5541.7	263.8
¼	8.295	10.21	20	314.16	62.83	50	1963.5	157.0	85	5674.5	267.0
½	9.621	10.99	½	330.06	64.40	51	2042.8	160.2	86	5808.8	270.1
¾	11.044	11.78	21	346.36	65.97	52	2123.7	163.3	87	5944.6	273.3
4	12.566	12.56	½	363.05	67.54	53	2206.1	166.5	88	6082.1	276.4
½	15.904	14.13	22	380.13	69.11	54	2290.2	169.6	89	6221.1	270.6
5	19.635	15.70	½	397.60	70.68	55	2375.8	172.7	90	6361.7	282.7
½	23.758	17.27	23	415.47	72.25	56	2463.0	175.9	91	6503.8	285.8
6	28.274	18.84	½	433.73	73.82	57	2551.7	179.0	92	6647.6	289.0
½	33.183	20.42	24	452.39	75.39	58	2642.0	182.2	93	6792.9	292.1
7	38.484	21.99	½	471.43	76.96	59	2733.9	185.3	94	6939.7	295.3
½	44.178	23.56	25	490.87	78.54	60	2827.4	188.4	95	7088.2	298.4
8	50.265	25.13	26	530.93	81.68	61	2922.4	191.6	96	7238.2	301.5
½	56.745	26.70	27	572.55	84.82	62	3019.0	194.7	97	7389.8	304.7
9	63.617	28.27	28	615.75	87.96	63	3117.2	197.9	98	7542.9	307.8
½	70.882	29.84	29	660.52	91.10	64	3216.9	201.0	99	7697.7	311.0

RULES FOR USING PERCENTAGE

To find the *percentage* of any number when the *rate per cent is given*:—Multiply the number by the rate per cent and set the decimal point two places to the left.

Example: Find 7.5 per cent of 35. 35 × 7.5 = 262.5, decimal point moved two places to the left gives Ans. 2.625.

To find what *rate per cent one number is of another*. Add two ciphers to the percentage and divide by the number on which the percentage is reckoned.

Example: What per cent of 75 tons is 9 tons? 900 ÷ 75 = 12 Ans. 12 per cent.

To find a number when the rate per cent and the percentage is known.—Add two ciphers to the percentage and divide by the rate per cent.

Example: If 68 pounds is 15 per cent of the entire charge, how many pounds in the total charge? Ans. 6800 ÷ 15 = 453.33 pounds.

To find what number is a certain per cent *more* or *less* than a given number.

When the given number is *more* than the required number add two ciphers to the number and divide by 100 plus the rate per cent.

Example: 465 is 35 per cent more than what number? 46500 ÷ (100 + 35) 135 = 344.4. Ans.

When the given number is *less* than the required number add two ciphers to the number and divide by 100 minus the rate per cent.

Example: 526 is 23 per cent less than what number? 52600 ÷ (100 − 23) 77 = 683.116. Ans.

CONVENIENT DATA FOR STORAGE CALCULATIONS

CUBIC MEASURE

1728 cubic inches = 1 cubic foot.
27 cubic feet = 1 cubic yard.

SQUARE BOX MEASURE

A box 24 × 16 inches and 28 inches deep contains 1 barrel
" " 16 × 16¾ " " 8 " " " 1 bushel
" " 8¼ × 8¼ " " 4 " " " 1 gallon
" " 4 × 4¼ " " 4 " " " 1 quart

21 cubic feet of river sand will weigh 1 ton
22 " " " pit " " " 1 "
28 " " " stiff clay " " 1 "

USEFUL FACTORS

Inches × 0.08333 = feet
Square inches × 0.00695 = sq. feet
Cubic inches × 0.00058 = cu. feet
Cubic inches × 0.004329 = U. S. gallons
U. S. gallons of water × 8.33 = pounds
U. S. " " " × 231.00 = cu. inches
Pounds " " × 27.72 = cu. inches
Ounces " " × 1.735 = cu. inches

WEIGHT CALCULATIONS

Weight of round iron per foot = Square of diameter in quarter inches multiplied by .1666
Weight of flat iron per foot = Width × thickness × 10.3
Weight of plates per sq. ft. = 5 pounds for each ¼ inch in thickness.
Weight of chain = Diameter squared × 10.7 (approximate).
Safe load (in pounds) for chain = Square of quarter inches in diameter of bar.

To compute weight of metal from weight of pattern; no allowance for cores or runners.

	Pattern of White Pine	Pattern of Mahogany
For Cast iron	× 16.7	× 10.7
" Brass	× 18.	× 12.2
" Lead	× 23.	× 15.
" Tin	× 15.	× 9.
" Zinc	× 16.	× 10.4

Weight of brass pattern × .9 = weight of iron casting approximately.

TABLE OF SPECIFIC GRAVITIES AND WEIGHTS OF METALS

Material		Specific Gravity	Weight per Cubic Inch (Pounds)
Water at 39.1 deg. F.		1.	.036
Aluminum		2.6	.094
Antimony, cast	6.64 to 6.74	6.7	.237
Bismuth		9.74	.352
Brass, cast	7.8 to 8.4	8.1	.30
Bronze	8.4 to 8.6	8.5	.305
Copper, cast	8.6 to 8.8	8.7	.32
Gold, pure, 24 carat		19.25	.70
Iron, cast	6.9 to 7.4	7.21	.263
Iron, wrought	7.6 to 7.9	7.77	.281
Lead		11.4	.41
Mercury at 60 deg. F.		13.58	.49
Platinum	21. to 22.	21.5	.775
Silver		10.5	.386
Steel, average		7.8	.283
Spelter or Zinc	6.8 to 7.2	7.	.26
Tin, cast	7.2 to 7.5	7.35	.262

PRESSURE IN MOLDS

For depths below pouring basin varying from 1 inch to 12 feet.

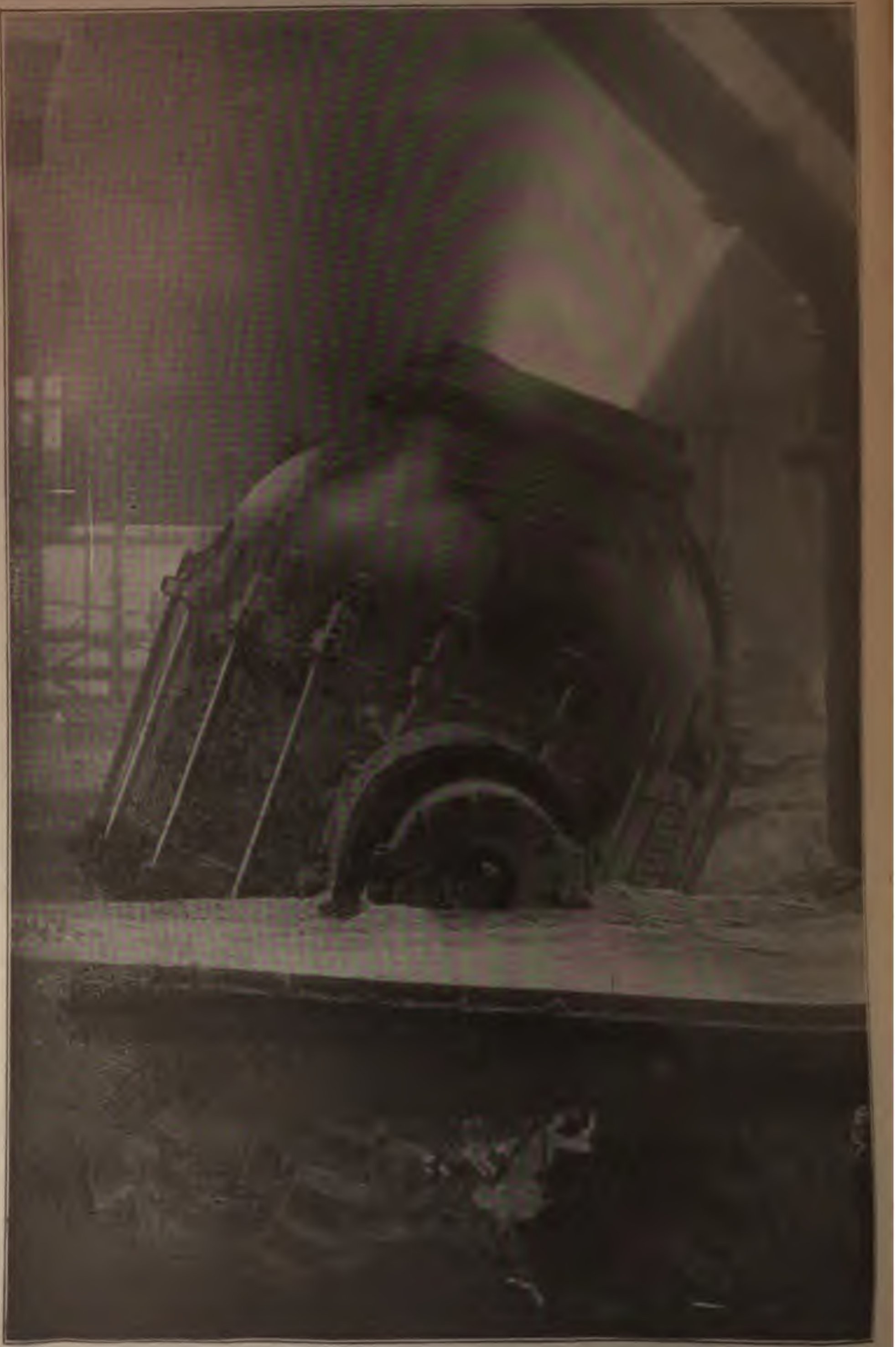
Depth Ft.	Depth In.	Pressure per Sq. In.	Depth Ft.	Depth In.	Pressure per Sq. In.	Depth Ft.	Depth In.	Pressure per Sq. In.
	1	.26		19	4.94	3	6	10.92
	2	.52		20	5.20	4		12.48
	3	.78		21	5.46	4	6	14.04
	4	1.04		22	5.72	5		15.60
	5	1.30		23	5.98	5	6	17.16
	6	1.56	2	00	6.24	6		18.72
	7	1.82		25	6.50	6	6	20.28
	8	2.08		26	6.76	7		21.84
	9	2.34		27	7.02	7	6	23.40
	10	2.60		28	7.28	8		24.96
	11	2.86		29	7.54	8	6	26.52
1	00	3.12	2	6	7.80	9		28.08
	13	3.38		31	8.06	9	6	29.64
	14	3.64		32	8.32	10		31.20
	15	3.90		33	8.58	10	6	32.76
	16	4.16		34	8.84	11		34.32
	17	4.42		35	9.10	11	6	35.88
1	6	4.68	3	00	9.36	12		37.44

To find total lifting pressure on cope multiply pressure per square inch at given depth below pouring basin by area (in sq. inches) of the surface acted against.

TEMPERATURES

From Late Scientific Investigations.

		Degrees Fahrenheit
Core ovens—approximate		250 to 450
Bright iron becomes	Yellow	435
	Purple	500
	Indigo	550
	Gray	750
Tin melts		445
Mercury boils		660
Lead melts		612
Zinc melts		775
Silver melts		1,775
Copper melts		1,885
Gold melts		1,900
Iron bar red in	a dark room just visible	950
	ordinary office	1,075
	daylight open air	1,450
Cast iron melts	white	2,075
	gray	2,230
Steel melts		2,750
Annealing malleable iron		1,600 to 1,750



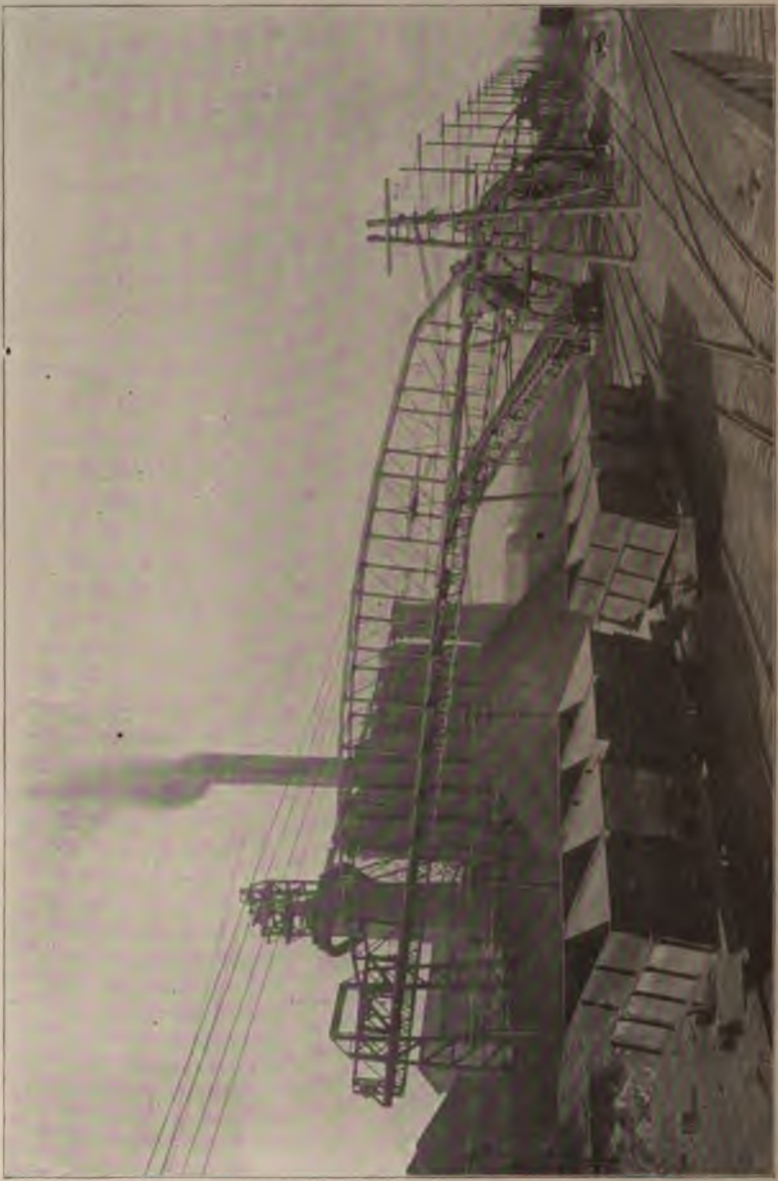
A BESSEMER CONVERTER IN FULL BLAST. TURNING IRON INTO STEEL.

AUTOMATIC APPLIANCES FOR HANDLING COAL AND IRON ORE.

During the past quarter of a century there has been a rapid, continuous, and truly phenomenal development in the means and methods for handling coal and iron ore in the transit from mine to furnace, or, in other words, from Mother Earth to the finished product. To so high a state of perfection have the utilities employed in the handling of these bulk commodities been brought, that the dawning years of the twentieth century find practically the entire movement from mine to market accomplished solely by mechanical means.

Surpassing as the achievements of the past score and a half of years have been in labor-saving, and consequently in the cost of handling iron ore and coal, they have not been more wonderful than the economies of time effected by the more rapid handling of the world's two most important minerals. It is indeed a great step from the old method of trundling small loads of the bulk material back and forth in wheelbarrows, to the new plan of transferring a carload of coal per minute, or to the moving of ore by means of grab buckets that scoop up automatically anywhere from two to ten tons at each operation; and yet, as has been said, less than thirty years has been required to work this amazing transformation.

The conditions governing the movement of iron ore and coal in the United States are peculiar in that several rehandlings are necessary. The major portion of the iron ore is mined in the States of Minnesota, Wisconsin, and Michigan; transported by rail to ports on Lakes Michigan and Superior; and then loaded on vessels which in some instances carry it to blast furnaces located directly on the shores of the inland seas, but which more frequently transport it to harbors on the south shore of Lake Erie, where there is a transfer from the vessels to railroad cars, in which the ore is moved to the blast furnaces of that great iron-manufacturing section known as the "Pittsburg District." Here, finally, there is still another rehandling when the ore which has been placed in stock piles is, as occasion requires, conveyed to the furnaces The



ORE-HANDLING APPARATUS AT BLAST FURNACE.

anthracite coal from the Pennsylvania field, and the bituminous fuel from the mines of Ohio, Pennsylvania, and neighboring States, which are shipped to points in the West and Northwest, traverse in the opposite direction practically the same route followed by the iron ore, and are subject to the same rehandlings.

The pioneer inventor who successfully solved the problem of handling coal and iron ore over a considerable range of distances solely or largely by mechanical means, was Mr. Alexander E. Brown, the well-known American engineer, the machines of whose invention are to this day accepted as the standard—and are indeed the sole—means of performing many of the functions in this highly specialized field.

BRIDGE TRAMWAYS.

At the outset, all the operations of transferring iron ore from ships to cars or stock piles, as the case might be, and of both loading and unloading coal-carrying vessels to and from cars or stock piles, were confined to a single class of apparatus—hoisting and conveying machinery of what is known as the "bridge tramway" type; and this form of handling appliance is yet so extensively used in moving both commodities as to merit first attention aside from its claim by reason of priority of invention.

A bridge tramway is, in effect, a miniature elevated railway along which loads are conveyed by the trolley system now so extensively employed in the industrial field. The skeleton bridge structure—supported at both ends by piers—is built of iron and steel designed to give the maximum strength with the minimum weight of material, and with all members made of such shapes, and so arranged in the trusses, as to offer the least possible surface to wind-pressure—an important consideration owing to the exposed locations in which these structures are generally used.

The bridge tramways proper usually range from 180 to 192 feet span; but, extending from the front pier, is a 34-foot apron reaching from the front of the dock out over the vessel tied up for unloading, while from the rear pier is a cantilever extension stretching back from 80 to 104 feet additional. Thus an area more than 300 feet wide is served by the tramway. The piers are of steel construction, and are high enough to support the bridge on an incline with the front end about 27 feet above the ground and the rear end 52 feet above the level. The piers are mounted on wheels running on tracks, so that the whole structure may be "skewed" or moved sideways back and forth along a dock to suit the hatches of a vessel. Thus a vessel may be unloaded by having several bridge tramways operating simultaneously over as many different hatchways, or openings in the deck; or the cargo may be removed by a single tramway adjusted so as to operate in first one division of the hold and then another, by means of the sidewise movement of the apparatus.

Running along a track suspended from the bridge between the girders, is a trolley with suspended bottom block and hook to which is attached the hoisting or pulling line, and all the motions of which are under perfect control of the operator by means of suitable levers. Up and down this trolley line, at a speed of hundreds of feet per minute, travels an iron tub or bucket in which the ore or coal is carried. These buckets are made in various sizes; but what might be termed the standard size has a capacity of seventeen cubic feet (or a gross ton) of ore.

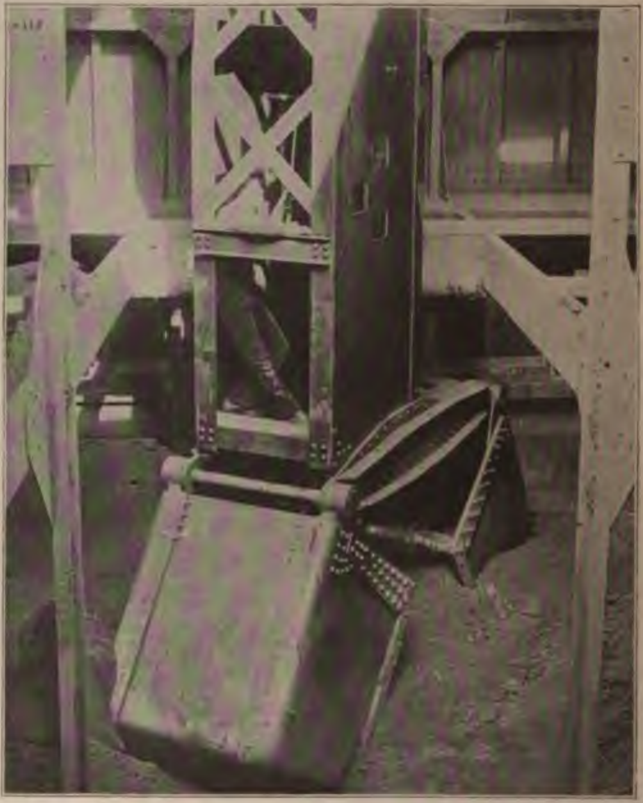
The plan of operation is practically the same in all cases. If coal or iron ore is being unloaded from a vessel, the operator, upon receiving from the hold of the vessel a signal that a tub is filled, throws the proper lever, and hoists the bucket at full speed through the hatch of the boat, the bottom block hooking automatically into the trolley, and the trolley carrying the heavily laden bucket to a point on the bridge or cantilever where its progress is arrested by dumping-irons placed at any desired location. These irons automatically trip the latch of the bucket, allowing it to upset, discharge its load, and automatically right itself. As soon as this is done, the operator releases the lever, and the bucket returns by gravity to its starting point in the hold of the vessel. The block unhooks automatically from the trolley, allowing the bucket to be lowered into the hold, whereupon the empty bucket is unhooked and a filled one hooked on. If preferred, the operator, instead of allowing the bucket to dump automatically, can lower it to any desired point for discharge, this being desirable when it is the purpose to transfer the coal or ore directly to waiting railroad cars.

One of the buckets such as have been described, will make a round trip from the hold of a vessel to the end of a bridge tramway trolley line, and return—a distance of 600 feet—in one minute; and in actual work a rate of forty-five seconds per round trip has been averaged for hours at a time. If the filling, handling, and hooking-on of buckets be done with reasonable dispatch, a single machine will readily transfer 400 gross tons of ore per day of ten hours. The cost of handling coal and ore by this means varies from seven-tenths of a cent to two cents per gross ton.

The first bridge tramway plants were erected on the iron-ore unloading docks at Cleveland, Ohio, about twenty-five years ago, and the new machines were for a time confined in their sphere of usefulness to the empire of the Great Lakes. Gradually, however, they secured general adoption, particularly for coal handling; and they are now to be found, not only on the Atlantic and Pacific coasts, but in Germany, Austria, Russia, Sweden, Egypt, and other foreign countries. Perhaps the best exemplification of the possibilities of this Yankee invention for coal handling, is afforded at the coaling stations of the United States Navy at Key West, Dry Tortugas, Mare Island, Cal., and New London, Conn., where, by means of bridge tramways such as have been described, fuel is transferred directly from storage buildings (having a capacity of 10,000 tons each) to the holds of United States war vessels.

GRAB BUCKETS.

During the early history of the bridge tramway plants, there was universal employment of tubs or buckets which, although self-dumping, had to be filled by hand. As an improvement upon these, there have been introduced various types of self-filling and automatic dumping buckets which will handle from two-thirds to four-fifths of a cargo or consignment of the bulk material without hand-shoveling. The most primitive forms of these self-filling buckets were "shovel" buckets of five tons' capacity, which scooped up their load through being dragged against the slope of the coal or ore pile. Then came the "grab" buckets, descending with open jaws, which, closing, took from the ore or coal pile a "bite" of one ton or more and held the material securely until released at any desired point of discharge. This class of buckets was introduced, not only in connection with the familiar bridge tramways, but also in conjunction with wire-rope cableways. The latter have been utilized to some extent for coal and ore handling, in locations where the necessary span was greater than could be successfully covered by a suspension structure of the weight of a bridge tramway



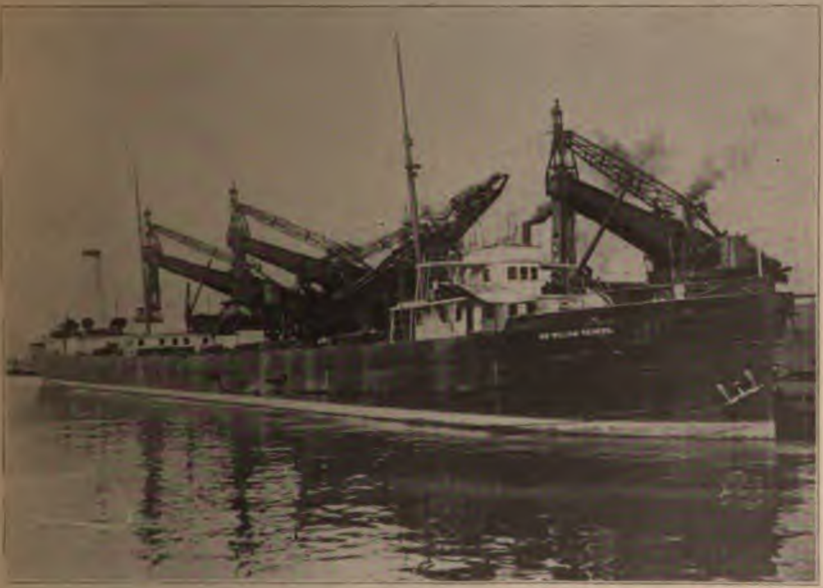
"CLAM-SHELL" BUCKET FOR AUTOMATIC UNLOADING.
Showing Operator in Mast.

CLAM-SHELL BUCKETS.

The most recent advances in ore-handling machinery have been along the development of appliances possessing the fundamental principle involved in the grab bucket above mentioned. The supreme triumph in this field is found in the recently devised automatic ore unloader, which, by means of a clam-shell attachment—an enlarged edition of the grab bucket—will take ten tons of ore from a ship's hold at each operation, and by means of which it is possible to remove every ounce of ore from a cargo-hold, thus dispensing entirely with hand shoveling, and eliminating the last utilization of manual labor in the handling of the raw material, from the time it is mined by means of a steam shovel until it is mechanically dumped into the blast furnace.

THE HULETT UNLOADER.

The Hulett automatic ore unloader, as the most perfect of these new appliances is known, is a machine which weighs fully 400 tons and has a height of 55 feet. It consists primarily of a foundation trestle, which is mounted upon wheels and which can be moved along the dock, the rails carrying the forward end of the trestle being directly on the brink of the dock, as in the case of the bridge tramways. Moving backward and forward on this foundation span, at right angles to the dock, is a heavy walking beam, attached to the outer end of which is the depending leg or



HULETT AUTOMATIC ORE UNLOADERS TAKING ORE FROM A LAKE VESSEL.

mast that carries the clam-shell bucket used in dipping out the ore. The parallel motion keeps the leg always in a vertical position; and the weight of the end of the walking beam, from which the bucket is suspended, is counterbalanced by means of a hydraulic accumulator located at the opposite end.

To operate this ingenious apparatus, the walking beam is run forward until the depending leg is suspended directly over the deck of the vessel. Then the mast, which revolves in a complete circle and in which the operator is stationed, is lowered through a hatchway and turned in any direction, its radius being fully nine feet. When open, the clam-shell bucket has a spread of 19 feet. After the bucket has been closed by hydraulic power, it is lifted from the boat and run back over the dock, where its contents can, if desired, be discharged directly into the railroad cars which are to convey the ore to the blast furnaces. Only three men are required to operate one of these machines, which has a capacity of 250 tons per hour.

The world's record for the rapid handling of an ore cargo was made a short time ago at the port of Conneaut, Ohio, when four of these machines, in a total working time of 4 hours 43 minutes, removed from the steamer *James H. Hoyt* a cargo of 5,300 tons of ore. All the cargo was taken out by the machines, no cleaning up whatever by hand labor being necessary.

FURNACE HOISTS.

The usefulness of new marvels for handling bulk materials is by no means confined to the transfer of coal and iron ore to and from ships, railroad cars, and stock piles, but is demonstrated in scarcely a less striking manner at blast furnaces and iron and steel making plants in general. Foremost among the utilities in this field is the furnace hoist and stock-distributer, which has done away entirely with the old-time dangerous and unsatisfactory method of feeding blast furnaces, and, by automatically charging the furnaces, dispenses entirely with the employment of top-fillers.

This hoist consists, in the main, of an inclined steel-trussed bridge starting from a pit and reaching to the top of the shell of the furnace, where it terminates in an extension over the top of the bell and hopper. A skip car with a capacity of from 2,000 to 6,000 pounds is arranged to run on this track, the hoist rope passing over the top sheave and back to the drum of the hoisting engine near the incline. When the skip car loaded with iron ore, coke, or limestone, as the case may be, arrives at the top of the furnace, the car is automatically tipped, and the load is dumped into the great receptacle, from which the belt has been automatically lifted for the purpose.

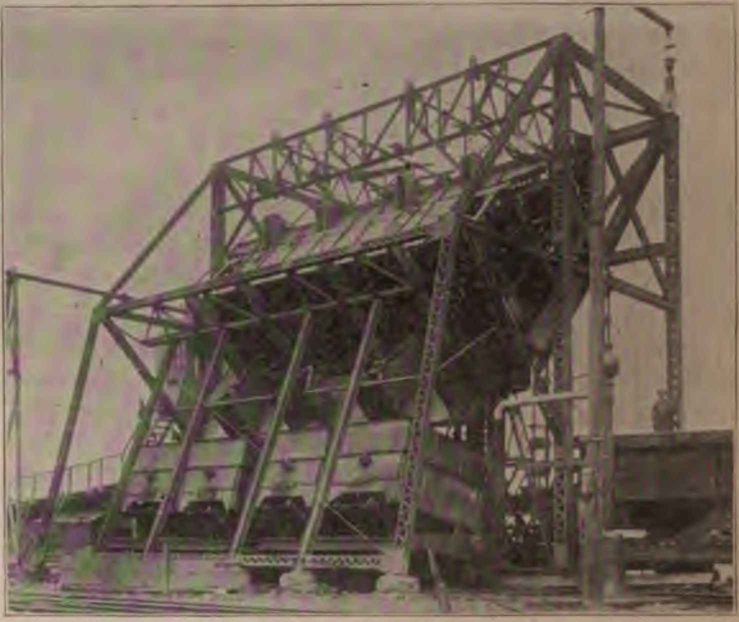
At all blast furnaces the transfer of iron ore from stock or storage piles to furnace as the raw material is required for consumption, constitutes a handling problem of some complexity. In this work there are employed steam shovels, locomotive derricks equipped with grab buckets, and, finally, various modifications of the bridge tramway. Some of the bridges thus employed have a clear span of about 250 feet over storage yard and railroad tracks, thus enabling the ore to be handled directly from railroad cars to furnaces, or from the stock piles where the surplus supply is held.

CAR-DUMPING MACHINES.

Yet another form of apparatus which is being employed in handling both coal and iron ore, is the car-dumping machine. At the furnaces these dumpers are utilized in some instances to transfer the contents of standard-sized railroad cars to smaller cars which carry the material to the furnaces; but the true province of this type of apparatus is in transferring coal (for water shipment) from cars to colliers. In this field they have found extensive utilization.

There are many different designs of car-dumping machines; but the most efficient styles are those which pick up and completely overturn the loaded car, transferring its contents to the hold of the vessel to be loaded. The earliest forms of car dumpers, while entirely satisfactory in the rapidity with which they handled material, were considered deficient in that they entailed a serious breakage of the coal. This, however, was finally remedied by modifications whereby the coal is dumped into pans connected with chutes leading to the vessel, which not only enable the fuel to be handled with far less breakage than formerly, but also make it possible to direct the influx to any portion of the hold desired.

The fundamental feature of the average car-dumping machine is a car-tipping device or cradle into which the car is run and then



A MODERN CAR-DUMPING MACHINE.

clamped, and which turns over with the car and discharges its contents. In some machines the receiving pan is automatically tilted at an angle proportionate to that of the car-tipping device, so that the coal slides gradually instead of pouring or falling; and in certain machines the coal is not sent into the vessel hold through a chute, but is transferred from the car, as it is dumped, to transfer tubs or to steel buckets arranged on the endless-chain plan, which convey it to the cargo space by easy stages and with practically no breakage. Some of these car-dumping machines will handle upward of 200 loaded cars in an ordinary working day, not only actually transferring the coal, but handling the loaded and empty cars to and from the machine, and obviating all necessity for the employment of a shifting engine and train-crew.

COAL-LOADING MACHINES.

An ingenious type of coal-loading machine is found at Fairport on the south shore of Lake Erie, and at several other points in the United States. By its operation the coal to be loaded on a boat is dumped from the hopper-bottomed railroad cars into a large receiving hopper underneath the car. From this hopper the fuel is delivered to a carrier of the continuous type, which hoists it up to an incline spout down which it passes into a telescope spout and thus directly into the boat. This telescope spout is drawn out to its full length at the commencement of operations, and is then gradually taken up or shortened as the boat is filled. By this means the spout is kept constantly full of coal, and the breakage of the fuel is reduced to a minimum. It requires but two men to operate such a machine, which is driven by a 50-horsepower engine. The cost of an installation of this kind is much less than in the case of some of the other types of coal-handling machinery, and yet such a machine is capable of loading from 600 to 900 tons of coal per hour.

REVIEW QUESTIONS.

PRACTICAL TEST QUESTIONS.

In the foregoing sections of this Cyclopedia numerous illustrative examples are worked out in detail in order to show the application of the various methods and principles. Accompanying these are examples for practice which will aid the reader in fixing the principles in mind.

In the following pages are given a large number of test questions and problems which afford a valuable means of testing the reader's knowledge of the subjects treated. They will be found excellent practice for those preparing for College, Civil Service, or Engineer's License. In some cases numerical answers are given as a further aid in this work.

REVIEW QUESTIONS

ON THE SUBJECT OF

PATTERN MAKING.

PART I.

1. What are some of the causes of warping in lumber?

2*a*. When is metal used for patterns?

2*b*. Why is metal better than wood?

3. Why should plenty of oil be used on an oil-stone?

4. Explain with sketch the method used in casting a small hollow cylinder.

5. For what parts of the pattern must the shrinkage rule be used?

6. Is the draft always the same on all parts of a pattern?

7. What is the usual allowance for finish on small castings?

8. When must a greater amount be allowed?

9. Under what conditions will a seasoned board warp?

10. What wood is most commonly used in pattern making?

11. Explain the difference in the manner in which saws cut when ripping and when crosscutting.

12. In what direction should the grindstone revolve when grinding scraping tools or other tools having a short bevel?

13. When is dry parting sand used?

14. Should a shrinkage rule be used when making a core box?

15. Why must the pattern maker know something of Mechanical Drawing?

16. When it is necessary to use a wide piece for a pattern, how may the tendency to warp be counteracted? Make sketch

17. Explain the use of the cap-iron of a plane.

18. What portion of the skew chisel does the cutting?

19. What is meant by shrinkage in pattern making?

20. How are the exact proportions of shrinkage obtained for different parts of the pattern?

21*a*. What is the usual proportion of draft to each twelve inches of surface on the face of a pattern for a cast-iron pulley?

21*b*. What proportions on the inside of the rim and on the hub?

22. When is it necessary to use mahogany, cherry, or maple for patterns?

23. What is lead in a plane-iron, and what determines the amount?

24. Explain the use of a flask in moulding, and describe the two principal parts.

25. What allowance must be made on the pattern for shrinkage when the casting is made of iron?

26. Explain what is meant by *draft* in pattern making?

27. How should lumber for patterns be seasoned?

28. When a large piece is to be used for turning, should it be cut from a plank of the required thickness or glued up out of thinner stock? Give reasons for answers.

29. Explain the methods of grinding the brad-awl and the advantages of each method.

30. Explain the use of core prints.

31. What is the allowance for shrinkage of brass?

32. What are the usual allowances for draft?

33. What is meant by *finish* in pattern making?

34. When gluing up pattern stock, how is the pressure necessary to bring the glued surfaces in close contact usually obtained?

REVIEW QUESTIONS

ON THE SUBJECT OF

PATTERN MAKING.

PART II.

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1. What are rapping plates?

2. Describe the process of gluing two thin pieces having large surfaces.

3. How is end wood treated if it is to be glued to other wood?

4. Explain why the upper core print sometimes has excessive draft, while the lower has but little draft.

5. What are fillets, and where are they used on patterns?

6. Give the dimensions for the arms of a six-arm pulley 40 inches in diameter and 12-inch face: (a) Width and thickness at hub. (b) Width and thickness at rim.

7. The pulley mentioned in Question 6 is to be fitted to a shaft $2\frac{9}{16}$ inches in diameter. (a) What should be the diameter of the hub? (b) What should be the length of hub?

8. What is a follow board, and when is its use necessary?

9. A pair of tight and loose pulleys 12 inches in diameter and $6\frac{1}{4}$ inches width of face, are to be fitted to a $1\frac{11}{16}$ inch shaft. (a) Give diameter of the hub. (b) Give length of hub.

10. What must be the outside diameter of the original wooden pattern for the rim of a pulley with six arms, the diameter of the finished pulley to be 30 inches and the width of face 9 inches?

11. (a) In the above pulley what should be the width and thickness of the arms at the rim? (b) What should be the width and thickness of the arms at the hub?

12. What are *core prints* and when do they form a necessary part of a pattern?

13. How are the two parts of a parted pattern held together for turning? Give two methods.

14. What are the proportions of alcohol and shellac gum for pattern maker's shellac varnish?

15. Is it always necessary to make a pattern in two parts?

16. How is colored shellac varnish made? (a) How is black made? (b) How red?

17. Give a sketch, including all dimensions, of the pattern for a plain brass cylinder which is to be finished "all over," the finished sizes being 6 inches long, 4 inches outside diameter, and $3\frac{1}{2}$ inches inside diameter. All shrinkage rule measurements, allow $\frac{3}{32}$ inch for finish.

18. What is a core box, and for what purpose is it used?

19. What is used to give a hard, smooth surface to a completed pattern?

20. What color should be used for the inside of a core box?

21. How can the pattern for a small hollow cylinder be moulded if made in one piece, (not parted)?

22. Why are core prints shellaced in a different color from the body of the pattern?

23. What are *dowel pins*, and why are they used in a parted pattern?

24. How long a time should each coat of shellac have for drying before another coat is applied?

25. Give sketch showing shape and dimensions of core box for pattern mentioned in Question 17.

26. It is required to make the pattern for a five-arm 15-inch hand-wheel, the rim and hub of which are to be turned and finished. The finished diameter of the round rim is to be $1\frac{5}{8}$ inches, and of hub $2\frac{1}{4}$ inches. Allowing $\frac{1}{16}$ inch for finish, give all dimensions for the wooden pattern, including width and thickness of arms at the rim and at the hub.

27. Give a sketch and all dimensions (shrinkage rule measurements) of the pattern for a cast-iron cylinder having a projecting flange, on each end (see Fig. 149), the cylinder to be bored out and finished all over, the finished sizes being as follows: Length 8 inches, diameter of flanges $5\frac{1}{2}$ inches, thickness of flanges $\frac{3}{8}$ inch, the diameter of the body of the cylinder outside 4 inches, and inside $3\frac{1}{4}$ inches, allowing $\frac{1}{8}$ inch for finish.

28. Can the above pattern be moulded without being parted?

REVIEW QUESTIONS

ON THE SUBJECT OF

MACHINE DESIGN.

PART I.

The drawings made in accordance with the problems below should be traced in ink on tracing cloth 18 by 24 inches in size, and having a border line ½ inch inside the edge of the paper.

PROBLEMS.

1. Suppose a 30-inch pulley is substituted for the 42-inch in the problem given, and that the pulley on the motor remains 10½ inches as before, how fast must the motor run to give the rope the same speed, 150 feet per minute?
2. Will the horse-power of the motor be changed with this new condition? Explain fully.
3. Calculate the width of double belt for above condition.
4. What is the torque on the motor shaft for above condition?
5. Calculate the size of shaft in the small pulley for above condition.
6. Calculate the size of shaft in the 30-inch pulley for above condition.
7. Design and draw both pulleys for above condition, making complete working drawings, and giving all calculations in full.
8. Taking the original problem as given in the text, suppose it is desired to increase the large gear to 45 inches diameter, calculate the load on the tooth, and a suitable pitch and face to take this load.
9. How many teeth must the pinion have to give the same speed of rope, 150 feet per minute, assuming that the motor runs 470 revolutions per minute, for condition in Problem 8?
10. Calculate the bore of pinion for this case.
11. Design and draw the gears for the conditions of Problems 8 and 9, giving all calculations in full.

12. When there is but 3,000 pounds on the rope, what are the tensions in each end of the brake strap, assuming that the size of drum and other conditions remain the same?

13. How much pressure on the foot lever would it take to hold this load of 3,000 pounds on the rope?

14. Suppose we put a bearing 9 inches long on the drum shaft; the distance, center to center of bearings, would then be 3 feet 8¾ inches, gears, drum, brake, and load being same as in the original problem of the text. Calculate the diameter of the drum shaft.

15. Suppose the height of bracket, center to base, to be 15 inches; length and diameter of bearing, as in Problem 14; and that we use a separate bracket for the drum bearings, not connected with the pinion-shaft bearings. Design and draw such a bracket.

16. Calculate, design, and draw all the parts for a machine similar to that of the text, from the following data:

Load on rope..................	4,000 pounds.
Speed of rope..................	175 feet per minute.
Length of rope to be reeled in....	250 feet.

Problem 16, is supposed to be worked out on the same lines as the text, but is wholly original in its nature, being based on entirely new data. It is not expected that this problem will be attempted except by well-advanced students who can give considerable time to working it out completely. It will be found, however, an excellent exercise in original and yet simple design.

REVIEW QUESTIONS

ON THE SUBJECT OF

METALLURGY.

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1. What is blister steel? How is it made?

2. What takes place when cast iron is made into wrought iron? Name the principal process.

3. Name three ores of iron with their approximate percentages of iron.

4. Why is the percentage of silicon important in iron castings?

5. What are the advantages of the Bessemer process of making steel? Of the Open Hearth process?

6. Explain the process for reducing iron ore to metallic iron. Give reaction.

7. What is the advantage of heating the blast of the blast furnace?

8. By what method is wrought iron made directly from the ore?

9. Give some of the qualities of pig iron. What chemical elements does it usually contain?

10. Why has mild steel replaced wrought iron? Why is wrought iron more easily welded than mild steel?

11. What is flux? What is slag?

12. Why does pig iron make good castings?

13. What is spiegel? State its use and approximate composition.

14. Describe briefly the Bessemer converter.

REVIEW QUESTIONS

ON THE SUBJECT OF

FOUNDRY WORK

PART I

1. Why is facing used on a mold?
2. What is the practical way to test the temper of molding sand?
3. What are chaplets?
4. What three forms of gases must be carried off by venting?
5. What is a skimming gate?
6. What are the properties of a good molding sand?
7. When making a large core what provision is made for handling it after baking?
8. How should a deep mold of heavy section be gated?
9. How are molds for pulleys usually gated?
10. What are risers?
11. What is the effect on the casting of ramming the mold too hard?
12. Name two means used to support the sand in the cope of a mold?
13. What are the common forms of chaplets?
14. How are the sides of deep molds vented when a flask is used?
15. What is the upward pressure on a cope where the exposed surface is 2 feet square and the depth 10 inches?
16. Why is blacking used on a core?
17. How are molds secured before pouring?
18. What are gaggers?
19. What precautions are taken in venting the sides and bottom of work which is bedded in the floor?
20. Name three important objects sought in venting a mold.

REVIEW QUESTIONS

ON THE SUBJECT OF

FOUNDRY WORK

PART II

1. What is meant by the sand bottom of a cupola? How is it formed?

2. How many thicknesses of fire brick is usually placed inside of the shell of a cupola?

3. In the design of a cupola, what bearing should the class of work to be poured have on the height at which the tuyères should be placed above the bed?

4. What are some of the precautions necessary in pouring a mold in order to obtain the best results?

5. Describe the operations in making a simple loam mold.

6. Having 65 per cent of a mixture settled upon, with a silicon content of 1.66 per cent, in what proportions could No. 1 and No. 3 irons be added, with silicon 2.65 - 1.75 per cent respectively, so that the castings should contain 2.25 per cent silicon? Deduct 20 per cent silicon for loss in cupola.

7. State the successive steps necessary in operating a cupola furnace.

8. How should the bed charge for a new cupola be determined?

9. What regulates the amount of fuel to be put between the charges of iron in a cupola?

10. What is the difference between the shrinkage of steel castings and that of iron?

11. What are some of the methods used to produce sound steel castings?

12. How is steel poured? What precautions are taken to prevent a mold for steel being "cut" by the rush of the metal?

13. What precautions are taken to prevent fracture at interior corners on steel castings?

14. How does the riser on a steel casting differ from one for iron?

15. What kinds of flasks are generally used for steel molds? Why?

16. What process are the larger steel castings put through to relieve internal shrinkage strains?

17. What are some of the properties of brass molding sand?

18. In what order are the metals for bronze melted?

19. What care must be used in melting and mixing brass?

20. What is the highest percentage of tin that may be mixed with copper and form a serviceable alloy?

21. What are the usual proportions of copper and zinc in yellow brass?

22. How is a common brass furnace constructed?

23. Why must copper alloys be melted without access of oxygen?

24. What is the best modern method of heating and ventilating a foundry?

25. What is the basis of Keeps tests; and what size bar is used for them?

26. What is the size of the test bar or "Arbitration Bar" so called, recommended by the American Foundrymens' Association; and how is it poured?

27. What is the advantage of overhead traveling cranes over jib cranes?

28. Where should the blower be placed in relation to the cupola?

29. What is the advantage of having the coke and iron storage on a level with the charging platform of the cupola?

30. How are floors for light work supplied with iron when at a distance from the cupola?

31. Where should the sand mixers be placed relative to the sand storage bins?

32. What points should be considered in locating the foreman's office?

33. In an 8 ton heat the first metal came down at 2:30 o'clock, the bottom was dropped at 4:15 o'clock. What was the rate of melting for that heat? (Divide tons by time in hours)

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